White Paper

Task Force 1: Building - User interaction

Topic B:

Occupant-centric building for enhanced quality of life

Revision: V2

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Disclaimer

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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 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. A first white paper discussed the acceptance and attractiveness of smart building solutions to end-users and is available via https://smartbuilt4eu.eu/publications/. The topic currently addressed by this task force and presented in this paper is ***occupant-centric building for enhanced quality of life.***

This topic focuses on the integration of smart building solutions with the aim to improve the comfort and health of occupants, but also the inclusiveness and accessibility of the building to people with more specific needs (elderly people, limited mobility, visually impaired, …). More and more smart solutions as well as some standards, certifications and public regulations are currently being developed to match some of these requirements, but a more global and systemic approach to this question of the overall quality of life within the building seems to be missing.

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

- Are there commonly agreed definitions relating to the quality of life in buildings, and what are the specific parameters behind the user centric building?
- What specific building and smartness parameters are attached to enhanced well-being, inclusiveness, and health?
- Beyond the existing standards, how can the quality of life (i.e. comfort, health and well-being) be enhanced through smart solutions?

In its first part, this paper provides a state of the art regarding the following issues, specific attention being paid to EC-funded projects:

- Definitions and dimensions of well-being in buildings
- Measurement framework related to quality of life in buildings
- Smart solutions for improved quality of life of building occupants.

This was followed by a brainstorming process enabling to identify some key barriers and drivers the above-mentioned scope. The next diagrams provide an overview of the main barriers and drivers discussed.

Figure 1: Overview of main barriers

BARRIERS	
TECHNICAL	**1. Difficulty to collect data about QoL:** lack of real-time measurements, intrusive sensors, time/effort to collect occupants' feedback, ambiguity on who should lead the data collection (company vs. facility managers vs. owners vs. individuals ….)
	2. Difficulty to quantify data about QoL: how to link perceived well being with measurements, lack of quantification methods, lack of indicators differentiated according to building segments
ECONOMIC	**3. Lack or willingness to pay for better comfort, lack of ability to anticipate the residual value of the smart solutions**
SOCIAL	**4. Subjective and evolving perception of comfort**, depending on culture, lifestyle, ageing, etc….
	5. Psychological dimension of wellbeing that goes beyond building-related factors (e.g. organisational aspects)
	6. Lack of understanding/knowledge by occupants about what wellbeing means for them and which building parameters influence it
VALUE CHAIN	**7. Fragmented offer**: lack of integrated smart solutions into the building to support well being and health; lack of standards to deliver personalised well-being services
	8. Lack of interest, knowledge and skills from installers, electricians, etc… about the relations between solutions performances and well being
REGULATION	**9. Concept of co-benefit still too vague and rarely monetised:** it is difficult to give a value to an improvement not directly related to energy savings.
	10. Unclear and/or constraining regulatory context with regard to data use (RGPD)

Top barriers according to the Task Force (barriers 1–9)

Figure 2: Overview of main drivers

DRIVERS	
VALUE CHAIN	1. Organisation image and reputation with regard to occupational well-being
	2. Certification schemes and voluntary schemes becoming the rule in some EU countries
	3. New business opportunities, with data-based business models requiring limited investments
SOCIAL	4. Evolving requirements regarding occupational working conditions: need to address new health threats (COVID), enable home office
	5. Social network and crowd sensing practices enable occupants to easily share their feedback
	6. Increased interest from occupants about comfort and health conditions in buildings
TECHNICAL	7. Availability of equipment to support the provision of health/well-being services
	8. Low cost and long-life sensors due to improvements in electronics
	9. New materials in buildings, whose impact on health/well being shall be monitored
REGULATORY	10. Deployment of smart meters
	11. Progressive consideration of well being indicators and criteria in regulations
	12. *Level(s)* European framework (providing common language to assess & reporting on buildings' sustainability performances) that includes health and comfort indicators

Top drivers according to the Task Force (drivers 1–4)

Based on the state of the art and the barriers and drivers, several research and innovation gaps were identified. They are synthetised in the next diagrams (the darker ones are those that were identified as priorities by the task force members).

Figure 3: Research and development gaps

R&D	1. Develop global methods & sensitivity algorithms linking (measurement) data and (comfort / well-being) KPIs.
	2. Propose a harmonised method to calculate the most common comfort indicators, integrating new KPIs related to non-energy benefits and privacy
	3. Improve human models for thermal comfort simulations, e.g. using wearables
	4. Develop/upgrade tools and processes to collect data on occupants well-being: from non-intrusive sensors, to smartphones and wearables and upgraded Post Occupancy Evaluation framework
	5. Strengthen the development of open-access databases of monitored buildings (sensors and occupants questionnaires)
DEMO	6. Identify living labs (large scale demonstration sites that have a longer lifespan than individual EU projects) and equip them with trust-worthy measurement tools to improve testing and validation
	7. Demonstrate applications of adaptive comfort models and occupant-driven strategies and technologies
	8. Use design thinking methods with users/customers for better defining objectives, data and further integrated functionalities

Key priority according to the Task Force (items 1–6)

Figure 4: Go-to-market gaps

REGULATION	9. Make the building logbook mandatory, with some items related to comfort, simplify regulation so it is easy to understand and verify
CERTIFICATION & STANDARDISATION	10. Deploy a user-centric standard that could be adopted at building's early design phase and based to European values and perspectives (e.g BREEAM, WELL)
	11. Make certification process easy, simple and accessible for all stakeholders, i.e. easy to present as part of the building documentation
	12. Consider evolutions of energy certification from a static picture to real time control and procedures
SCALING UP & INDUSTRLIALISATION	13. Develop pre-commercial procurement (with public entities)
	14. Map the smart solutions ensuring the monitoring and follow-up to requirements of sustainable buildings (DGNE, BREEAM, etc) and well buildings (WELL etc) to generate market expectations
	15. Facilitate contact and interactions between building owner, facility manager, building user
UPSKILLING & AWARENESS RAISING	16. Conduct "evangelisation" of occupants, property managers and insurers about smart technology benefits on well-being in buildings, necessary to create market demand (through education, information)
	17. Develop training, demos and social business cases towards electricians and installers on the relation between building solution performances and well-being perception

Key priority according to the Task Force

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

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List of abbreviations

AI	Artificial Intelligence
BDT	Building centered Digital Twin Environment
BEMS	Building Energy Management Systems
BIM	Building Information Modelling
BMS	Building Management Systems
DER	Deep Energy Renovation
EC	European Commission
ECM	Energy Conservation Measure
EEB	Energy Efficient Building
EMS	Energy Management Systems
EPBD	Energy Performance of Buildings Directive
EVCS	European Common Voluntary Certification Scheme
HUI	Human User Interface
IAQ	Indoor Air Quality
IEQ	Indoor Environment Quality
GDPR	General Data Protection Regulation
GIS	Geographic Information Systems
GWAC	GridWise Architecture Council
HVAC	Heating Ventilation and Air Conditioning
ICT	Information and Communication Technologies
IoT	Internet of Things
ML	Machine Learning
PEB	Plus Energy Building
QoL	Quality of Life
SIL	Safety Integrity Levels
SRI	Smart Readiness Indicator
TF	Task Force

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 all 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 aims 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 aims 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 and engaged end users of smart buildings:** this topic aims to investigate how smart technologies can trigger behavioural changes among end users to serve other purposes than their own quality of life (building operation optimization, resource efficiency, etc).

The present white paper focusses on the second topic, i.e.: "Occupant centric building for improved quality of life" 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

"We shape our buildings, and afterwards our buildings shape us"

Winston Churchill while debating the rebuilding of the House of Common
House of Commons, 28 October 1943

In the paper "10 questions about well-being in buildings "(2020), S. Altomonte et al. state:

"We need to begin with a paradigm shift in how we think about the built environment. Building performance standards and conventional building practice are all about 'reducing the negative'. The western goal of indoor environmental quality seems to be 'if no one notices, and no one complains, we're successful'. But what if the design goal was for occupants to notice the environment they live in, and in positive ways? "

This topic focuses on the integration of smart building solutions with the aim to improve the comfort and health of occupants, but also the inclusiveness and accessibility of the building to people with more specific needs (elderly people, limited mobility, visually impaired, …). More and more smart solutions as well as some standards, certifications and public regulations are currently being developed to match some of these requirements, but a more global and systemic approach to this question of the overall quality of life within the building seems to be missing.

TOPIC B within this task force therefore focuses on the following questions:

- Are there commonly agreed definitions relating to the quality of life in buildings, and what are the specific parameters behind the user centric building?
- What specific building and smartness parameters are attached to enhanced well-being, inclusiveness, and health?
- Beyond the existing standards, how can the quality of life (i.e. comfort, health and well-being) be enhanced through smart solutions?

2.2. Scope

As Figure 6 shows, three main blocks of knowledge were collectively selected to identify the most suitable pathways towards a better coverage of the concept of improved quality of life in buildings through smart solutions.

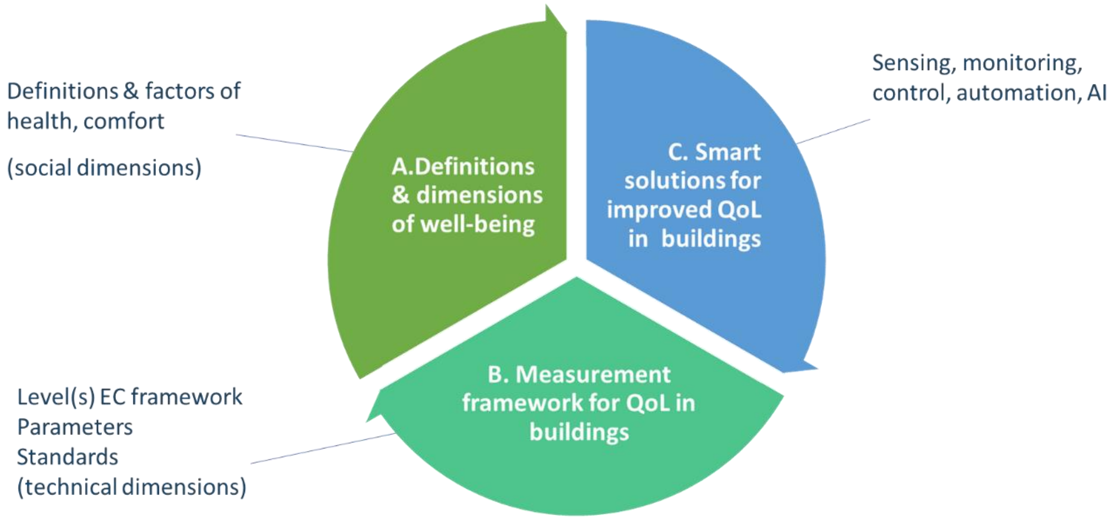


Figure 6: Blocks of knowledge identified

A. Definitions and dimensions of well-being in buildings

This block relates first to the scoping and definitions of the well-being in buildings, including the relation between comfort, health and well-being, and the recent paradigm shift from "do no harm to occupant" to "generate positive stimuli to occupant". Secondly, it covers the different factors that impact the perception of comfort in buildings, and how they can be modelled. The perception of comfort can vary according to countries (culture, geographical and climatic conditions), buildings type and use (residential vs occupational), social categories (children, working people, ageing population, etc), and personal factors (psychological and physical factors).

B. Measurement framework related quality of life (QoL) in buildings

This block covers the ongoing activities regarding standards, rating schemes, labels and certification that tempt to score building parameters related to occupants' well-being. This analysis provides the basis on which smart building solutions can build to propose monitoring and control services that can improve the well-being perception of occupants.

C. Smart solutions for improved quality of life in buildings

This block addresses the state of the art on smart solutions contributing to health and comfort in buildings, with specific focus on real-time monitoring of key parameters influencing the occupant's perception of well-being, and automation and (user-driven) control of these parameters, including self-learning capabilities.

3. State of the Art

3.1. Definitions and dimensions of well-being in buildings

In this paper, we will use the term *quality of life in buildings* to refer to the three dimensions of health, comfort and well-being in the built environment, as detailed below.

3.1.1. Scope and terminology associated to well-being in buildings

The literature has identified the lack of clear terminology regarding the concept of well-being. In a detailed scoping review of the conceptual approaches to well-being and buildings, M. Han (2018) points out a large heterogeneity of definitions. She identified the following topics related to well-being definitions:

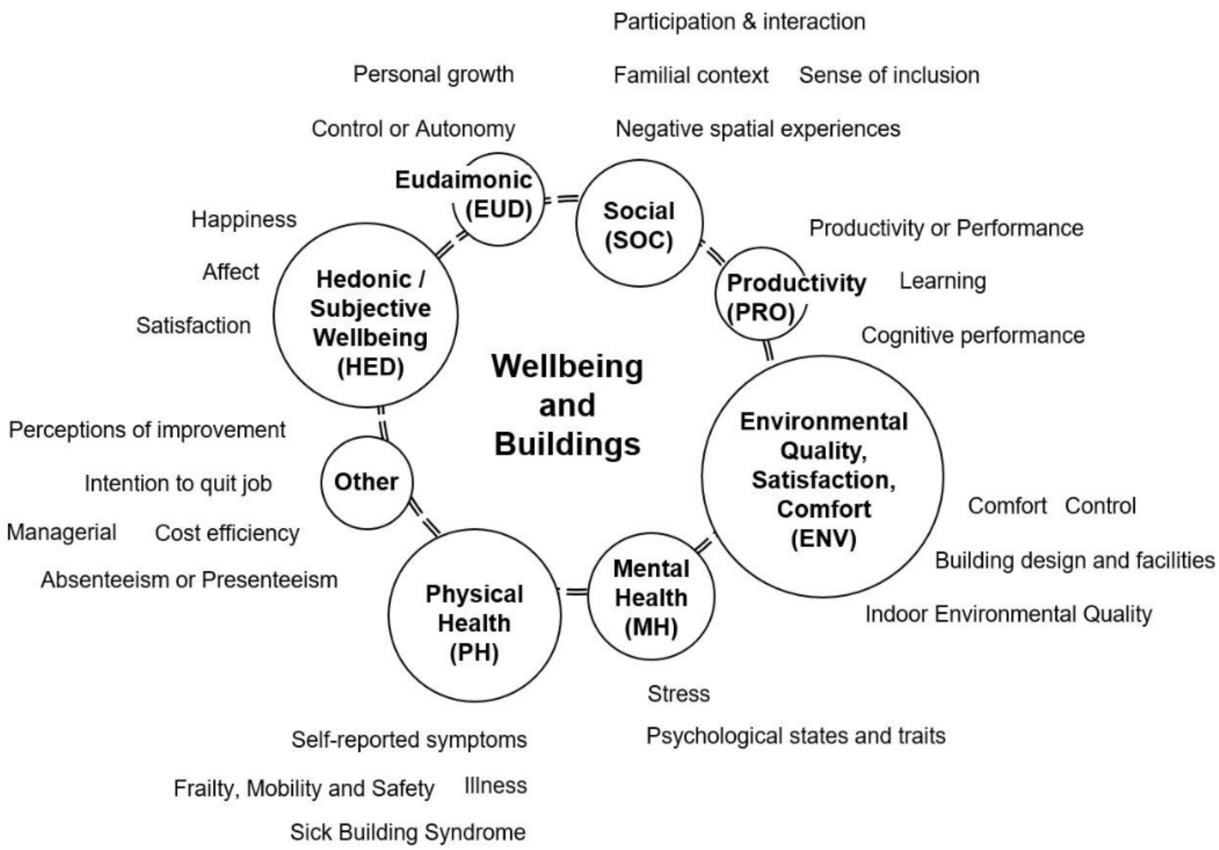


Figure 7: Well-being and building scoping review results: themes and subthemes (Han, 2018)

Based on detailed literature review of definitions related to indoor environment quality (IEQ), L. Rohde et al. (2019) propose a three-branched framework to define the good indoor environment inspired by the concept of the Vitruvian Triangle (from the architecture domain), equally relying on comfort, health and well-being. The authors propose the following definitions:

- **Comfort:** indoor environment conditions that facilitate a state of satisfaction of bodily wants in occupants, based on their individual preferences and their given activity, and that limit physical stressors causing annoyance.
- **Health:** indoor environment conditions that promote physical resilience and restitution of occupants, and limit physical stressors causing infirmity, disease, and years of potential life lost.
- **Well-being:** indoor environment conditions that afford mental resilience and restoration, offer variation, provide controllability, and advance positive stimuli to improve occupant happiness.

Figure 8: Three-branched framework to define the good indoor environment (Rohde et al, 2019)

The above definition of well-being results in a holistic interpretation of IEQ, with the introduction of positive stimuli leading to positive emotions, improving mental state, and promoting occupant happiness.

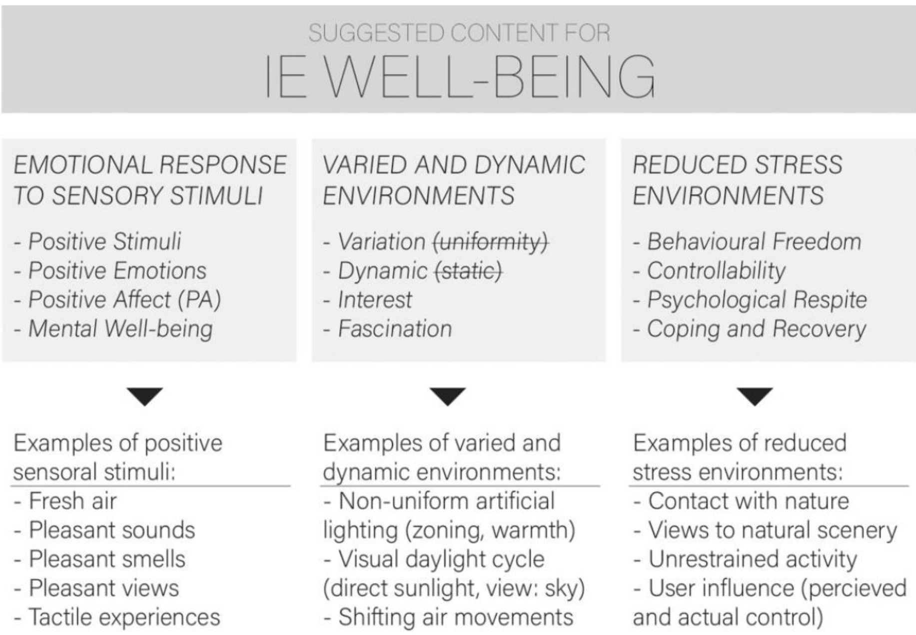


Figure 9: Diagrammatic content summary of the proposed well-being domain, including indoor environment (IE) examples (Rohde et al, 2019)

3.1.2. Modelling well-being

As a conceptual framework, S. Altomonte et al. propose a re-interpretation of Maslow's hierarchy of needs which suggests that we need to first satisfy our basic requirements for life at the bottom of the pyramid, breathing, food, etc., before we move upward to aspire towards higher desires for pleasure, love, etc.

This pyramid model is reinterpreted as a hierarchy of environmental experience, focusing on the area of thermal comfort, but applicable to other senses as well. At the lowest level, the goal is simply to avoid heat and cold stress as this is often the basis for occupational safety and health standards. Moving upwards, our buildings are generally operated to meet thermal neutrality. A familiar example is ASHRAE Standard 55, which prescribes conditions in which 80% of the occupants will find the conditions 'acceptable'. The third level reflects the idea of well-being, and how we can create environments that support our physical, social, and emotional health, our cognitive function, and productivity.

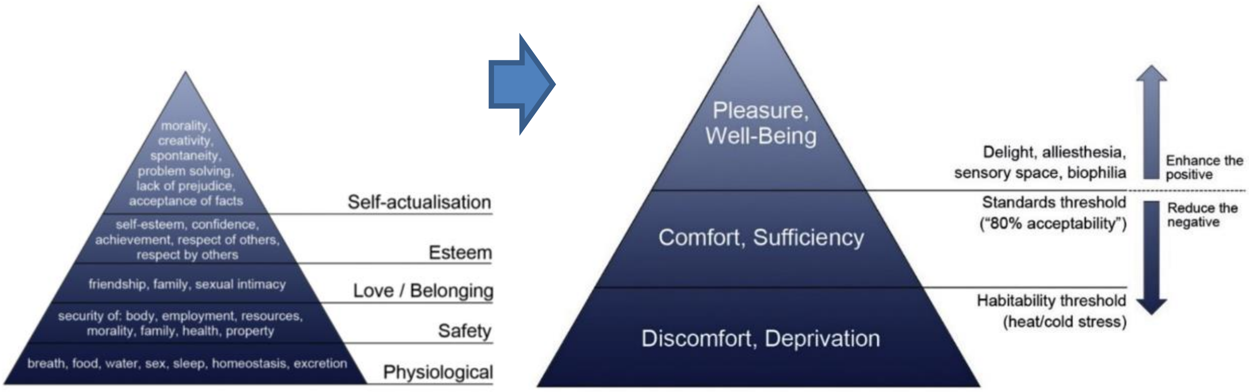


Figure 10 Re-interpretation of the Maslow hierarchy of needs for indoor spaces: spectrum of occupant experience (Altomonte, 2020)

P. Bluyssen (2020) states that the growing field of indoor health and comfort studies in schools, offices and homes, shows a discrepancy of IEQ current standards with end-users needs. Current guidelines for IEQ are based on single-dose response relationships[1], and on preventing diseases and disorders rather than focusing on positive effects. IEQ is assessed using indicators that do not consider different scenarios (e.g., homes, offices, schools, etc.) and situations (sitting behind a desk, in a meeting room listening on the phone, washing, cooking, sleeping, etc.), neglecting other stressors (physical, physiological, personal, psychological, and social) and their integrated effects over time.

Bluyssen proposes a new IEQ model to explain symptoms and complaints, preferences and needs, to prevent negative effects and stimulate positive experiences. This model is suitable for determining patterns of stressors and interactions and takes account of dynamic behaviour over time per scenario.

[1] The dose–response relationship, or exposure–response relationship, describes the magnitude of the response of an organism, as a function of exposure (or doses) to a stimulus or stressor (usually a chemical) after a certain exposure time

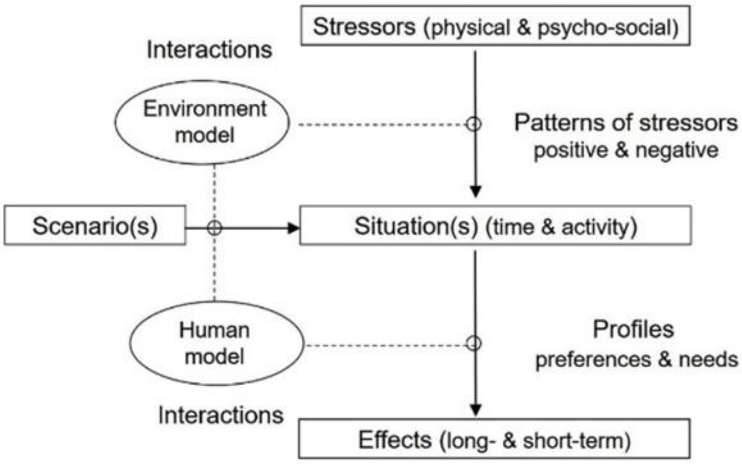


Figure 11: New IEQ model for the integrated analysis approach (Bluyssen, 2020)

3.2. Measurement framework for quality of life in buildings

3.2.1. Building parameters influencing occupant's comfort and related building requirements

Literature reviews showed that occupant comfort is affected by various indoor environmental conditions as well as outdoor conditions, building characteristics and occupant-related characteristics. The next diagram synthesises the key parameters affecting indoor environment quality.

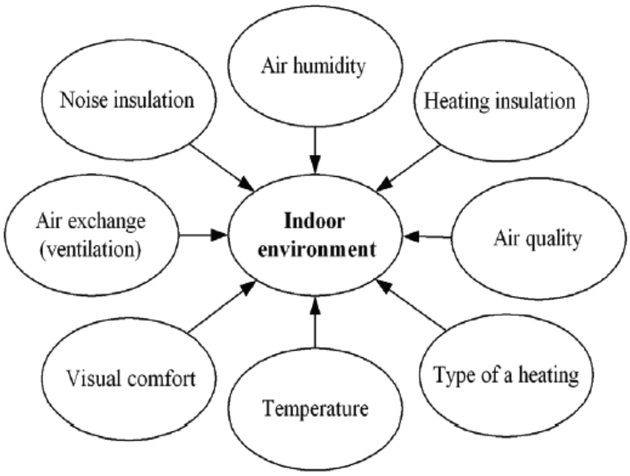


Figure 12: Diagram synthesizing the key parameters affecting IEQ

Among those parameters, luminous, thermal, acoustic, and indoor air quality (IAQ) have proven to influence user perception at most. However, the relations between indoor environment parameters and the perception of well-being and comfort by different, individual occupants are complex and require further investigation.

On this base, a key smartness features of buildings to achieve improved comfort, health and well-being for occupants is the ability to provide:

- **flexible and adaptable settings**: this implies to consider how these settings might change over time, responding to diverse purposes, accommodating varied requirements, being transformed based on user profiles and needs, and how the role of occupants might evolve from passive to active, aware and engaged inhabitants.

- **local control**: this may be in the form of hands-on adjustments to conditions that are available to the user, or adjustments made by an automated system based on user settings.

At a different level, we should also clearly consider **data privacy** as part of the comfort parameters for building occupants in Europe. Compared to other regions where data privacy is little considered but the smart building solutions market much more mature, Europe has set strong data privacy limits that are linked to its cultural framework.

3.2.2. EC Level(s) approach to healthy and comfortable spaces

Level(s) is the EC framework to provide a common language for assessing and reporting on the sustainability performance of buildings. Level(s) offers an extensively tested system for measuring and supporting improvements, from design to end of life. It can be applied to residential buildings or offices.

Level(s) is made up of 6 macro-objectives and 16 performance indicators. Macro-objective 4 is called "Healthy and comfortable spaces", and includes performance indicators on Indoor Air Quality, time outside of thermal range, lighting and visual comfort, and acoustics and protection against noise, as shown below.

4. Healthy and comfortable spaces	4.1 Indoor air quality	Parameters for ventilation, CO2 and humidity Target list of pollutants: TVOC, formaldehyde, CMR VOC, LCI ratio, mould, benzene, particulates, radon
	4.2 Time outside of thermal comfort range	% of the time out of range during the heating and cooling seasons
	4.3 Lighting and visual comfort	Level 1 checklist
	4.4 Acoustics and protection against noise	Level 1 checklist

Figure 13: indicators related to health and comfort in EC Level(s)

3.2.1. ASHRAE standard 55 and the adaptative comfort model

Standard 55 developed by American Society of Heating and Air-Conditioning Engineers (ASHRAE) specifies conditions for acceptable thermal environments and is intended for use in design, operation, and commissioning of buildings and other occupied spaces.
In its latest version, the standard includes a separate adaptive model for determining acceptable thermal conditions in occupant-controlled naturally conditioned spaces. Based on various empirical and experimental investigations, the module considers that the internal air temperature can be calculated by considering several factors such as the interaction of the inhabitants with their surroundings, including when they change their clothes, opening/closing windows, the use of low-energy fans, drinking water, and drawing shades. One of the key results of such adaptive theory is that people living in warmer climates can tolerate warmer temperatures indoors than those living in colder climates.
Experiments showed that adaptive thermal comfort decreased the requirement for heating or cooling by almost 50% of the time when compared with the fixed settings of temperature limits for air-conditioning units. This may ultimately lead to reduced energy consumption, running costs, and a reduction of the GHG emissions over the lifecycle of the building.

3.2.2. Labels, ratings and certification schemes

We owe to mention the different schemes that propose to score the building performances in terms of well-being, as listed below. However, the limit of such approaches is to propose a 'static' evaluation of the building performances with regard to well-being, where the continuous monitoring possibilities offered by smart building solutions can enable a dynamic assessment of such parameters.

- BREEAM (Building Research Establishment Environmental Assessment Method), the world's first sustainability rating scheme for the built environment, focuses on measuring and reducing the impacts of buildings and in doing so, create assets that are better for people and the environment
- The Leadership in Energy and Environmental Design (LEED) rating system provides a framework for healthy, highly efficient and cost saving green buildings. It is for all building types and all building phases including new construction, interior fit outs, operations and maintenance and core and shell.
- The WELL Building Standard™ (WELL) was the first building standard to focus exclusively on the health and wellness of the people in buildings. It is a performance-based system for measuring and certifying features of buildings that impact human health and well-being, through air, water, nourishment, light, fitness, comfort and mind. It marries best practices in design and construction with evidence-based medical and scientific research – harnessing buildings and communities as a vehicle to support human well-being.
- The FITWELL standard provides tailored scorecards for existing and new buildings and sites. It counts seven health impact categories: impact on surrounding community health; reduction of morbidity and absenteeism; support to social equity for vulnerable populations; feelings of well-being; access to healthy foods; occupant safety; increases physical activity.

Research is ongoing to propose schemes that combine and/or complete the different elements of the above ones, such as:

- IEQ-Compass – A tool for holistic evaluation of potential indoor environmental quality
- comfort classification indexes suitable for both single environments and whole buildings

3.3. Smart solutions that can contribute to improve quality of life of occupants in buildings

As mentioned above, the key smartness requirements that could lead to improved well-being of building occupants are:

- Real-time monitoring of key parameters influencing the occupant's perception of well-being as there are known today. This includes both building parameters and occupants' physical and psychological parameters.
- Both automated and user-driven controls of these parameters, including self-learning capabilities.

This section provides an overview on available technologies and solutions to meet these requirements.

3.3.1. Context aware buildings

First, some definitions as a reminder below:

Pervasive or ubiquitous computing can be defined as "the physical world that is richly and invisibly interwoven with sensors, actuators, displays, and computational elements, embedded seamlessly in the everyday objects of our lives, and connected through a continuous network" (Weiser et al., 1999). Other terms such as ambient intelligence or "everyware" are also used for this same concept.

Contextual awareness: "A system is context aware if it uses context to provide relevant information and/or services to the user, where relevance depends on the user's task". Dey (2001) defines context as "Any information that can be used to characterise the situation of an entity".

Context aware buildings therefore adapt to human behavior to adjust dynamically comfort (and improve energy). It relies heavily on sensing the environment, acquiring information about users, and actuating equipment. Sensing and actuation have been facilitated by the development of Wireless Sensor Networks and the Internet of Things (IoT). Such systems can rely on sensing devices that are either:

- **worn by the occupants**, such as mobile phones or **wearables**. For example, it is possible to locate and count people using Bluetooth technology on their mobile phones. Wearables can measure the methabolic state of users through heart frequency and send this information. Wearables represent a concrete path to integrate human with buildings.
- integrated into the building (e.g., temperature, CO2, window lock, etc.). However, no one wants to live in a house full of sensors, even more since they need maintenance. Therefore, their number should be kept minimum, the key point is to use them at best for control applications.

Deploying **context awareness** in buildings implies to interconnect these IoT devices with the Building Energy Management System (BEMS) control and have the ability to detect occupant activity and behavior. While there are plenty of IoT solutions in the market, the decision as to which solution to deploy depends primarily on the existing BEMS and whether it is an open or closed source solution.

3.3.1. Individual comfort models through human in the loop mechanisms (AI-based)

Several studies have recently been directed towards developing individual/personal comfort models based on Artificial Intelligence and/or Machine Learning techniques and users' personal characteristics within a given environment. For example, a decision support framework is proposed for personal thermal comfort prediction in real time, especially for senior citizens, using environmental, psychological, and physiological features. Results showed a significant improvement in predictive accuracy (76.7%) compared to the conventional model (35.4%) by including two new factors: age and outdoor temperature. In other personalised models, both thermal comfort and energy savings are addressed through a "human-in-the-loop" approach that allows HVAC to be adapted to user preferences. Smart-phone application can help to dynamically track the optimal conditioning mode in a single or multi-occupied area, the reduction in uncomfortable reporting is almost 53.7%.[2]

While most studies so far focused on office environments with healthy adults as occupants, a few of them address elder people and dwellings. Recent experiments with such models, that rely on deep learning algorithms and environmental and personal characteristics as inputs, indicate that approaching thermal comfort through individualised models can significantly improve comfort predictions of older people in their own homes. Such AI-based systems for context awareness mechanisms and individual comfort models are very promising, but still at low maturity stage, partly due the fact that this type of algorithms typically needs a massive quantity of high-quality real-world data, which buildings and the energy sector so far don't have.

3.3.2. Assets and limits of current sensing, automation and control solutions

About sensing and monitoring technologies related to well-being, one can note:

- A strong trend towards cost decrease in sensing devices, and related increase of device numbers and functions: e.g. smartwatches with increasing number of health sensors (sleep patterns, stress levels, heartbeat, SpO_2 etc.).

[2] Intelligent Building Control Systems for Thermal Comfort and Energy-Efficiency: A Systematic Review of Artificial Intelligence-Assisted Techniques, Halhoul Merabet et al.

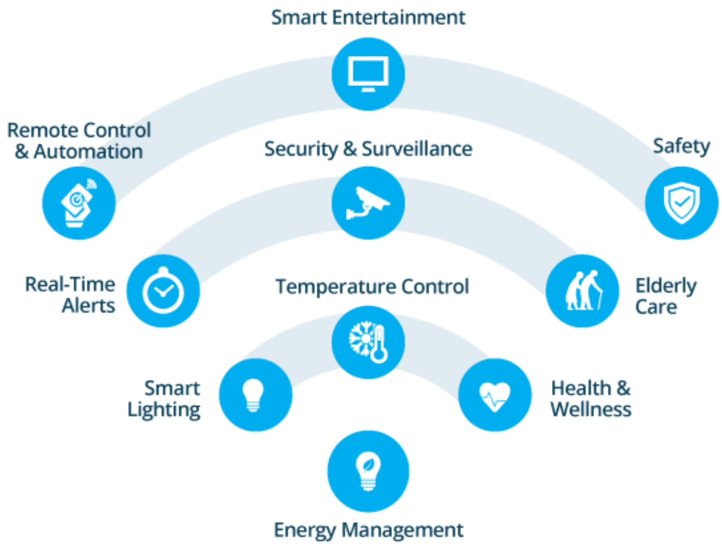
- Increasing connectivity (5G, LiFi, Photonics) that enable massive communication of data between IoT devices, and improvements in the technical management of data privacy (Safety Integrity Levels (SIL), see SPHERE project).
- Protocols as Zigbee and wireless sensors fed with batteries (no cables needed). The deployment of these solutions can be quick and effective, and batteries can last more than 6 months.
- The deployment of some IAQ devices in specific segments, i.e., schools
- Dashboarding solutions, services and platforms enabling users to aggregate information from different sensors and sources. However, such user interfaces are not always used by end-users, or they are used only for an initial short period of time.
- Apps for crowd sourcing or crowd sensing that are based on the voluntary sharing of information by users.
- Some lack of customization capabilities of existing products, and lack of integrated solutions combining services related to several aspects related to the built environment (e.g. health and energy efficiency).

About automation and control related to well-being, one can note:

- Commercially available automation services, targeting user comfort and safety (lights and temperature control, indoor presence detection, etc.), as well as notification services to inform occupants about IAQ conditions. Most of solutions are coupled with hardware (thermostats, purifiers, motion detector).
- The development of IoT/Edge computing and AI-based solutions for both comfort and security: "home tune-up" based on user needs, moods, and health; pattern recognition.
- Automation advances in capturing and collecting end-users' feedback on perception of the end-users for the spaces they are occupying, that will contribute to design new solutions in the future construction.
- Interaction devices to enable communication between building and occupants

A specific point of attention is privacy management. While some services start getting more customised in Europe, the GDPR constraint seem to appear as a limit to user profiling. This shows a strong different with e.g. the Chinese market, where privacy is far less considered, and smart solutions in buildings far more developed.

Figure 14: Existing smart applications for well-being in homes[3]



[3] source: https://www.webnms.com/iot/smart-buildings-home-automation.html

3.4. Lessons learnt from Horizon 2020 projects

3.4.1. Overview

The next diagram clusters the EC-funded project identified by the task force members, according to their respective focus, i.e. building occupants perceptions and behaviours, smart solutions and their integration, needs of ageing population, energy management.

Figure 15: Relevant H2020 projects identified by the task force members

The next sections tempt to synthetise some key lessons learnt from the most relevant projects in relation to this paper topic.

3.4.2. Lessons learnt from the UtilitEE project

UtilitEE provides a consumer-oriented universal behavioural change framework that focuses on the discovery, quantification and revelation of energy-hungry behaviours/activities and conveys meaningful energy-use feedback to users to motivate and engage them into a continuous process of learning and improvement. It is an innovative human-centric behaviour change framework based on scientific state of the art, along with standardised operational rating and certification methods, facilitated by an open and trustworthy ICT ecosystem integrated into the building through low-cost, off-the-shelf sensors.

Main conclusions: In the field of comfort and well-being, main focus towards the extraction of comfort profiles on the basis of indoor environmental conditions. The main interest is the incorporation of comfort profiles at energy efficiency management strategies on the way to ensure a comfort preserving energy savings framework

Key lessons learnt include:

- The extraction of accurate comfort profiles requires a lot of data from actual conditions
- The set-up of sensorial equipment is very important
- The calibration of the sensors as well as the personalization of services is very important

- There is a high potential towards the provision of comfort preserving services to the building occupants

3.4.3. Lessons learnt from the SPHERE project

SPHERE project targets the improvement and optimization of the building's lifecycle: energy design, construction, performance and management of residential buildings, reducing construction costs and their environmental impacts while increasing overall energy performance. SPHERE seeks to develop a building centered Digital Twin Environment (BDT), involving not only the design and construction of the building but also including the manufacturing and the operational phases.

Main conclusions: Residential Building Digital Twin functional representation requires a new professional role, the BDT Simulation Manager, that must be well coordinated with BIM and other services of the BDT. Advanced software in the loop embedded in supervision and control devices improves drastically the visibility of health, comfort and energy parameters. Human models and occupancy interaction with the building, using wearables and smart sensors to receive the human presence and status, are key elements for functional simulation and implementation of advance control of the building, not only thinking on energy savings but considering health and comfort implications.

Key lessons learnt include:

- Human models are crucial since the "standard" human does not exist. Therefore, taking care of specific behaviour of age or gender together with general real-time parameters as activity level or clothing is a must.
- Defining an objective level/region of comfort for each human is required for automatic control or regulation of building's systems.
- An advance control does not mean more sensors, but less and more trustable instrumentation.
- BDTs require the explicit consideration of diverse requirements in its design to become trustworthy to their users and to society at large. Robustness and privacy deserve a careful consideration, since the BDT may collect data from people or linked to people, and the actions or decisions on the physical environment may in turn affect people. Trustworthiness should be included as a critical requirement in the conception, planning, design and construction of every BDT (and not after the system is built or deployed).

3.4.4. Lessons learnt from the BIM SPEED project

The BIM-SPEED project aims to improve energy efficiency of the existing buildings by means of Building Information Modelling (BIM) to reduce the planning, execution, engineering time, and costs of renovation projects. One of the project objectives is to collect inhabitants' input from an existing building to complement the required input for further analyses and simulations, especially in relation to the comfort of inhabitants.

Main conclusions:

Inputs from the inhabitants are essential to detect the changes and weaknesses of an existing building as well as to develop optimal renovation strategies. Among the tools offer, the 'Inhabitants crowd-sourcing' app aims to collect data on existing Buildings from inhabitants. A collected series of questions is distributed from the back office to the relevant participating inhabitants who will respond using a freely downloadable mobile app. One of the specific needs of the app was the BIM viewer where the space-based interaction was added to allow users to select spaces instead of elements and filter based on the floor. This tool is suited for the design renovation and occupation and maintenance phase.

Key lessons learnt include:

- Data collected through this app is seen as vital as it produces data based on lived-experiences of occupants which are not easily achieved through sensors or monitoring equipment.
- To deal with privacy and ethical concerns, inhabitant-informed consent informs participants about how their data are collected and used by the project.
- Inhabitant participation in the BIM SPEED process should be seen as both an asset and a liability and the data produced treated with special attention.

3.4.5. Lessons learnt from the sustAGE project

sustAGE aims to develop a person-centred smart solution, fostering the concept of "sustainable work" for EU industries, thus supporting the well-being, wellness at work and productivity of ageing employees. The sustAGE solution will improve occupational safety and health via risk assessment and prevention strategies and will provide personalised recommendations for physical and mental health improvement, enhancing the individual's motivation and promoting well-being.

Main conclusions

Cameras, wristwatches, environmental and location sensors, integrated into daily devices and in the work environment, as well as users' speech comprise the list of data sources that feed the sustAGE IoT ecosystem. The interactions between workers and the system have been considered as the key micro-moments to assess workers' physical, mental and emotional state. Through the analysis of the data captured in these micro-moments, sustAGE suggests recommendations that contribute to an improvement in workers' health and well-being based on previous experiences.

Key lessons learnt include:

- To support the well-being, workers' ***physical, mental and emotional states*** are considered.
- The smartphone is the primary device for communication and multimodal interaction supporting natural language understanding and voice sentiment analysis.
- The adopted IoT configuration exhibits the advantages of unobtrusive user context interaction monitoring in a privacy-preserving way, since in private life, outside the working environment, only the wristwatch and the smartphone are used.
- The main requirements of the IoT management solution relate to interoperability, scalability, security and privacy of the communicated data.

3.4.6. Lessons learnt from the eTEACHER project

eTEACHER aims to empower building end-users to achieve energy savings and improve comfort for the sake of health and well-being. The project develops intervention strategies according to cultural and demographic indicators. eTEACHER took place in 12 different demo sites located in three European countries with different climatic conditions.

Main conclusions:

eTEACHER provides a very detailed analysis of end-users' behaviours on their pilot buildings, which include residential buildings, offices, health care centers and schools, covering both public and private buildings, a wide range of building user types and geographical contexts. Detailed analysis framework and data collection process to study building occupants' behaviour have been developed. The dataset includes energy-related behaviours and awareness, but also sources of discomfort (temperature, natural light), outdoor and indoor conditions, occupancy, windows opening, etc. IEQ enhancement related to temperature, relative humidity and CO_2 levels have been identified in every pilot building and can be linked to the use of eTEACHER tools.

Key lessons learnt include:

- Solutions to save energy may compromise comfort levels. eTEACHER solutions must evaluate the possibilities to select the best Energy Conservation Measures (ECMs) and propose tailored energy interventions.
- Reliability of the sensors used, and the data quality are critical to monitor the enhancement of indoor environmental quality and behavioural changes
- Sensors' battery is an important problem.
- Privacy is an issue regarding the acceptance of eTEACHER sensors

3.4.7. Lessons learnt from the MOBISTYLE project

MOBISTYLE aims to raise consumer awareness and motivate behavioural change, towards optimised energy use, by providing attractive personalised combined knowledge services on energy use, indoor environment, health and lifestyle, by ICT-based solutions. One objective is then to combine energy monitoring with monitoring indoor environment and behaviour parameters.

Main conclusions:

The building users have been categorised in a generic way into several MOBISTYLE user profiles (archetypes). The driving forces of energy-related occupant behaviour have been ordered according to the following categories***:*** **biological driving forces, psychological driving forces, social driving forces and external driving forces** (time, building and building equipment properties, indoor and outdoor physical environment).

Key lessons learnt include:

- Ethnography is used as a type of anthropological inquiry that investigates lifestyles with qualitative techniques (participant observation, focus groups, etc). This approach enables to gain an in-depth understanding of human behaviour, which can penetrate beyond the quantified behaviour of 'big data', collected via technological solutions.
- Health and well-being is a much broader category than just physical activity. People put a lot of attention on their mental health and emphasise food and cooking as an important element of a healthy lifestyle.
- Habits and long-lasting practices are formed in communities, neighbourhoods, and circles of friends through peer pressure, and in families and educational institutions.
- Self-defined user profiles: enabling a possibility for the users to actively cooperate in creation and setting-up of their own profiles.
- Users should be able to adjust various parameters influencing his or her indoor comfort through the same IT-based solution.
- Technological saturation and cognitive overload with information is a very important issue that has to be taken into account when designing new technologies

3.4.8. Lessons learnt from the Cultural-E project

Cultural-E develops technologies and solution sets that are tailorable to specific contexts and energy demands, as well as performing a comprehensive optimisation of the value/cost ratio of Plus Energy Buildings.

Main conclusions:

The Cultural-E project has developed the European Climate and Cultural Atlas for Plus Energy Buildings (PEBs) Design – the 2CAP-Energy Atlas, an online tool to help designers, researchers and policy makers to understand how different European local climates and cultures can influence energy demand in buildings.

Key lessons learnt include:

- A critical review of standards for indoor thermal environment and air quality shows that the comfort level depends on the type of occupants, the room, and the type of activities.
- The most common methods to study preferences related to air quality and thermal comfort and interaction between users and the installations seems to be qualitative interviews performed with a selection of residents and web-based questionnaires/surveys with residents in selected residential areas
- Adaptative standards for thermal comfort and sustainability for PEBs design may be considered and modelled based on the cultural and climatic specificities.

3.4.9. Lessons learnt from the Homes4Life project

Homes4Life aims to stimulate investment in age-friendly homes and improve opportunities for ageing well in place for the European population, by both defining and offering a holistic, positively framed long- term vision for inclusive housing in Europe and offering practical tools in the form of certification.

Main conclusions:

Homes4Life developed a certification framework for age-friendly buildings, in collaboration with end users. The project precisely documented the needs of elderly people and translated them in clear requirements than can be re-used for further development of smart solutions related to ageing, and more largely also to take account of elderly people's expectation when designing smart building solutions.

Key lessons learnt include:

- In the Homes4Life taxonomy, comfort definition is broader than temperature regulation and air quality. It also includes daylight and artificial light quality and acoustic properties (insulation) taking control over the environment.
- The importance of the home environment to people's emotional well-being, sense of anchoring and sense of self is well-attested. The home is an important part of who and what people are, and this importance increases with age, as people spend more time in their home (up to 90% of the time in the "oldest old" i.e. those over 85 years of age), and as memories centered around the home continue to accrue.
- The need that older people experience is for a comfortable home they can get around in, with an immediate outdoor environment of quality.
- Being unable to maintain one's home is as a major barrier for some older people: home maintenance is essential to ensure a safe and healthy environment.
- To ensure physical safety and comfort, the smart readiness of the dwelling permitting digital services is important.

3.4.10. Lessons learnt from the ALDREN project

ALDREN is a methodological framework that implements the European Common Voluntary Certification Scheme for non-residential buildings (EVCS), with 4 standalone modules and 2 reporting tools. One of the objectives of ALDREN project is to document the quality of indoor environment (IEQ) in the building undergoing deep energy renovation process to document potential benefits for health and well-being as a result of a deep energy renovation process.

Main conclusions:

A health and well-being assessment protocol, based on an index called the ALDREN-TAIL index, was developed to document and rate the Indoor Environment Quality of buildings (office buildings and hotels) undergoing deep energy renovation (DER) as well as to predict IEQ during the design of DER. It focuses on 4 key components: T= thermal environment, A= acoustic environment, I=indoor air quality and L= luminous (visual) environment. Recommendations regarding renovation practices relevant to these 4 environments have been provided by the project.

Key lessons learnt include:

- An extensive review of the indicators proposed in green building certification schemes, standards, sustainability framework and air quality guidelines were crucial to select the 12 parameters of the TAIL index, and make sure that it corresponds to a real preoccupation of all professionals in the search of complete evaluation of a building quality.
- TAIL ratings can and should be evaluated before and after renovation.
- Because the TAIL index should guarantee a good IEQ after the energy renovation, it must also be possible for the building owners or investors to assess what could be the influence of the different renovation actions on IEQ thanks to prediction models

3.4.11. Lessons learnt from the SHAPES project

SHAPES intends to build, pilot and deploy a large-scale, EU-standardised open platform, integrating a broad range of technological, organisational, clinical, educational and societal solutions to improve the health, well-being, independence and autonomy of older individuals, while enhancing the long-term sustainability of health and care systems in Europe.

Main conclusions:

Utilizing a human-centred co-design process, basic personas with their prototypical attributes, attitudes, behaviours and characteristics as well as general use cases including scenarios of use of digital solution have been developed to guide the development of the SHAPES solutions. Moreover, a set of 22 heuristics and recommendations have been proposed to guide user interface design of digital solutions targeting older persons in specific applications domains or web, mobile and multimodal support.

Key lessons learnt include:

- To develop personas, focus on the intersection of functional and emotional needs with medical and personal needs: “Live my Life, Love my Life, Manage my Health and Feel Understood” (in ref of the intersection of needs from Bhattacharyya et al., 2019)
- This combination has the potential to orient care so that it can better manage the coping with life in the elderly.
- designing digital products for older persons, the following heuristics should receive greater emphasis: Ergonomics/dexterity, reduced memory load/cognition, Visual and auditory presentation, Preferable gesture, and accommodating altered touch and temperature perception and restricted mobility and balance.

3.5. Other initiatives related to enhanced quality of life in buildings

Some national R&I projects also provide significant achievements, briefly detailed below:

- LIST launched a research project entitled Post Occupancy Evaluation SYstem (POESY), to tackle issues surrounding uncomfortable or inefficient buildings. The system collects feedback from occupants, data from sensors, connects them to the Building Information Model and gives a centralised overview of a building. It will then be compared to what the architects and engineers planned in their simulation before construction to achieve a certain set of parameter performance.
- Another interesting project from LIST is the SemanticLCA project that aims to attenuate the environmental impact of our buildings trough Semantic-based Dynamic Life Cycle Assessment. The project looks at the trade-off amongst health & well-being, and energy efficiency thanks to a new generation of life cycle assessment methods and tools that are model-based (based on BIM) and

continuously informed by dynamic/real-time data. It supports life cycle decision making and active control of buildings and districts.

- Brains 4 Buildings (B4B) focuses on energy efficiency and flexibility in smart buildings taking into account the user. The project adds operational intelligence to buildings in order to achieve a transition towards energy-efficient and flexible buildings. The project intends to validate integrated prototypes of software plug-ins for:
  - smart monitoring and control of buildings and installations,
  - increasing controllable energy flexibility in buildings, applied to multi-commodity buildings.

  Another objective of the B4B project is to validate prototypes of data-driven and user-centric user interfaces that contribute to user comfort, health and well-being.
- KIRA-digi (FI) implements the key projects concerning the digitalisation of public services. The project extends BIM to building maintenance and boosts the digitalisation of the built environment and construction sector.
- Refresh: Remodeling Building Design Sustainability from a Human Centered Approach (UK) aims to put the human at the centre of building performance and to develop new measures and models that better capture the complexity of these interactions. Impacts of the project include quantitative evidence for the inter-relationships between people, their buildings and the urban microclimate, a new sustainability framework for buildings, and advances in methods for measuring and modelling physical and human interactions, particularly in dynamic conditions.

Finally, other initiatives and innovations provide significant achievements and are summarised in the table below.

Name of initiative / innovation	Relevant inputs
Technology	
Focchi Curtain Wall System (IT)	Connected facade which integrates sensors in the facade for human comfort /well-being and energy consumption.
Haltian Empathic Building for smart office (FI)	Haltian Empathic Building for smart office solution focuses on improving employee well-being and happiness. A complete and end-to-end smart office solution that combines technology, culture and physical space into one. It focuses on employee experience instead of the building system and improves employees' interactions with the spaces, environment and technology.
Footbot Smart Air Building	Heating and cooling are the largest consumers in buildings but still, people inside often don't feel comfortable. To improve comfort or air quality, Foobot artificial intelligence suggests optimised HVAC actions and needs. It intends to achieve compliance with ASHRAE 55 "Thermal Environmental Conditions for Human Occupancy".
Airthings indoor air quality and radon monitors (NO)	All-in-one solution to monitor, identify and solve air quality issues for a healthier, more comfortable home/work environments.
Netatmo solutions (FR)	IoT solutions for a safer, healthier and more comfortable indoor environment
Cross-cutting initiatives	
IEA EBC Annex 79: Occupant-Centric Building Design and Operation	The IEA EBC Annex 79 aims to provide new insights into comfort-related occupant behaviour in buildings and its impact on building energy performance as well as occupant-centric building design and operation.

World Economic Forum's Real Estate community: A framework for the Future of Real Estate.	The World Economic Forum's Real Estate community has developed a vision for the future of real estate. It is a future in which buildings provide comfort, are equipped for the most unprecedented events, support people's health, and are affordable and accessible for all of society.

4. Barriers and drivers

4.1. *Barriers*

Barriers to the market uptake of smart building solutions enhancing well-being of occupants were reviewed and prioritised by the task force. The top barriers are highlighted below.

BARRIERS	
TECHNICAL	**1. Difficulty to collect data about QoL:** lack of real-time measurements, intrusive sensors, time/effort to collect occupants' feedback, ambiguity on who should lead the data collection (company vs. facility managers vs. owners vs. individuals ....)
	2. Difficulty to quantify data about QoL: how to link perceived well being with measurements, lack of quantification methods, lack of indicators differentiated according to building segments
ECONOMIC	**3. Lack or willingness to pay for better comfort, lack of ability to anticipate the residual value of the smart solutions**
SOCIAL	**4. Subjective and evolving perception of comfort**, depending on culture, lifestyle, ageing, etc....
	5. Psychological dimension of wellbeing that goes beyond building-related factors (e.g. organisational aspects)
	6. Lack of understanding/knowledge by occupants about what wellbeing means for them and which building parameters influence it
VALUE CHAIN	**7. Fragmented offer**: lack of integrated smart solutions into the building to support well being and health; lack of standards to deliver personalised well-being services
	8. Lack of interest, knowledge and skills from installers, electricians, etc, about the relations between solutions performances and well being
REGULATION	**9. Concept of co-benefit still too vague and rarely monetised:** it is difficult to give a value to an improvement not directly related to energy savings.
	10. Unclear and/or constraining regulatory context with regard to data use (RGPD)

Top barriers according to the Task Force

4.2. *Drivers*

The drivers identified by the task force are as illustrated next page.

DRIVERS		
VALUE CHAIN	1. Organisation image and reputation with regard to occupational well-being	*Top drivers according to the Task Force*
	2. Certification schemes and voluntary schemes becoming the rule in some EU countries	*Top drivers according to the Task Force*
	3. New business opportunities, with data-based business models requiring limited investments	*Top drivers according to the Task Force*
SOCIAL	4. Evolving requirements regarding occupational working conditions: need to address new health threats (COVID), enable home office	*Top drivers according to the Task Force*
	5. Social network and crowd sensing practices enable occupants to easily share their feedback	
	6. Increased interest from occupants about comfort and health conditions in buildings	
TECHNICAL	7. Availability of equipment to support the provision of health/well-being services	
	8. Low cost and long-life sensors due to improvements in electronics	
	9. New materials in buildings, whose impact on health/well being shall be monitored	
REGULATORY	10. Deployment of smart meters	
	11. Progressive consideration of well being indicators and criteria in regulations	
	12. *Level(s)* European framework (providing common language to assess & reporting on buildings' sustainability performances) that includes health and comfort indicators	

5. Gaps

Various activities required to overcome the barriers and leverage the drivers related to improve quality of life of building occupants through smart functionalities were suggested and prioritised by the task force members and are presented in Table 1. The priority ones according to the task force are in bold.

Table 1: Suggested R&I activities

Type of activity	Activities
R&I	▪ **Develop global methods & sensitivity algorithms linking (measurement) data and (comfort / well-being) KPIs. This includes the use of AI and self-learning systems** ▪ Improve human models for thermal comfort simulations. That means an anthropometric big effort in many EU countries to have specific values for temperature and ventilation problems. Wearables can help achieve this goal. ▪ Strengthen the development of open-access databases of monitored buildings (sensors and occupants' questionnaires) ▪ Propose a harmonised method to calculate the most common comfort indicators, to integrate them with new KPIs related to non-energy benefits (see ALDREN project and method), also including privacy ▪ Develop/upgrade tools and processes to collect data on well-being and identify priorities for occupants: develop non-intrusive sensors, use existing devices from occupants such as smartphones, user key cards (at work); focus groups on QoL; serious games; upgrade Post Occupancy Evaluation

	framework and processes (social science) using recent data-driven developments, and including methodologies to gather feedback from low-voice people
Demo	▪ Identify living labs (large scale demonstration sites that have a longer lifespan than individual EU projects, starting with tertiary sector - e.g. campus) and equip them with trust-worthy measurement tools to improve testing and validation ▪ Demonstrate applications of adaptive comfort models and occupant-driven strategies and technologies ▪ Use design thinking methods with users/customers for better defining objectives, data and further integrated functionalities
Regulation & legal framework	▪ **Make the building logbook mandatory, with some items related to comfort** ▪ Simplify regulation so it is easy to understand and verify
Certification & standardisation	▪ **Deploy a user-centric standard that could be adopted at building's early design phase and based to European values and perspectives (e.g BREEAM, WELL)** ▪ Make certification process easy, simple and accessible for all stakeholders, i.e. easy to present as part of the building documentation ▪ Consider evolutions of energy certification from a static picture to real time control and procedures
Scaling up & industrialisation	▪ Facilitate contact and interactions between building owner, facility manager, building user ▪ Develop pre-commercial procurement (with public entities) ▪ Map the smart solutions ensuring the monitoring and follow-up to requirements of Sustainable buildings (BREEAM…) and well buildings (WELL etc) to generate market expectations
Upskilling & awareness raising	▪ **Conduct "evangelisation" of occupants, property managers, insurers, about smart technology benefits on well-being in buildings, necessary to create market demand (through education, information)** ▪ Develop training, demos and social business cases towards electricians and installers on the relation between building solution performances and well-being perception

6. Conclusion

This document formalises the collaborative work performed by the members of SmartBuilt4EU task force 1, on a voluntary basis, during the period October 2021- May 2022. It also integrates the feedback collected during 1) a peer review conducted by VITO in February 2022, and 2) an open consultation process during in April-May 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 better integrate smart building solutions in view of improved comfort and health of occupants.

This White Paper will feed the elaboration of the Strategic Research and Innovation Agenda that the SmartBuilt4EU consortium will present to the European Commission.

Task Force 1 will investigate one more topic during 2022: next topic, starting May 2022, will focus on **Responsive end-users (tools and strategies to give operational feedback to occupant triggering behavioural change).**

If you have some expertise to share on this topic, you are invited to join the task force and contribute to the next White Paper (contact detail below).

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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8. Annex 1: list of H2020 projects reviewed

Table 2: list of relevant EU projects

Project	Status	Weblink	Relevant inputs
UtilitEE	Completed in 2020	https://www.utilitee.eu/	UtilitEE provide a consumer-oriented universal behavioural change framework that focuses on the discovery, quantification and revelation of energy-hungry activities and conveys feedback to users to motivate and engage them into continuous improvement. The incorporation of user preferences on the overall management of the building is a use case of the project
SPHERE	Ongoing	https://sphere-project.eu/	Building Digital Twins developed at SPHERE project integrates simulation models with humans interacting with the building. This interaction is simulated but could be implemented using wearables. The final interface of the complex AI implementation is quite simple in the digital twin, making possible the user involvement and the redesign of this interface based on specific building features.
BIM SPEED	ongoing	www.bim-speed.eu	The BIM-SPEED project aims to improve energy efficiency of the existing buildings by means of Building Information Modelling (BIM). One of the objectives is to collect inhabitants' input from an existing building to complement data in relation to the comfort of inhabitants, thanks to the 'Inhabitant crowdsourcing' app.
eTEACHER	Completed in 2020	http://www.eteacher-project.eu/about-the-project/	SoA on ICT-based engagement for energy efficiency; evidence-based approach for developing behaviour change interventions; Case studies of end-user behaviours in buildings
MOBISTYLE	Completed in 2020	https://www.mobistyle-project.eu/en/mobistyle	Analysis of behaviours connected to the use of buildings (italian and slovenian universities). A paper discussing the survey's findings was published on the 'EDP Sciences' website. • Recommendations for the ICT developers based on focus groups findings. • Develpoment of gamiefied app and dashboard Evaluation of campaings and tools effectiveness on users
sustAGE	Ongoing	https://www.sustage.eu/	**sustAGE** aims to develop a person-centered smart solution, in close collaboration with occupational specialists, psychologists and end-users, aiming to support the employment and later retirement of older adults from work.

			→ support employers and ageing employees to jointly increase well-being, wellness at work and productivity.
SHAPES	ongoing	https://shapes2020.eu	Older adult engagement in user-centered, innovative digital solutions for active and healthy ageing. The SHAPES Pan-European Pilot Campaign aims at engaging +2000 older adults and bringing forward technology to improve their health, well-being and autonomy. A user-centered interoperable SHAPES Technological Platform will be developed, including smart digital solutions tailored to health and care delivery.
cultural E+	Ongoing	www.cultural-e.eu	Cultural and climatic considerations are incorporated into the Plus Energy Building (PEB) designs, aiming at improving the post-occupancy energy performance of the building. The work is based on a literature review, the development of an online GIS tool, and 4 demonstration cases located in different European climatic regions.
Homes4Life	Completed in 2020	http://www.homes4life.eu/	Requirements and specifications for age-friendly housing; taxonomy, KPIs and proposal of certification scheme
ALDREN	Completed in 2020	https://aldren.eu/	Alliance for Deep Renovation in Buildings. ALDREN solutions associate low energy renovation of the non-residential building stock with high quality indoor environments, advocating for renovation while promoting health and comfort.
EPC RECAST	ongoing	https://epc-recast.eu/	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 IEQ, well-being and smartness.
PHOENIX	ongoing	https://eu-phoenix.eu/	The aim of the project is to address all aspects of the SRI covering also the provision of non energy services. Towards this direction, the establishment of a comfort and health environment through the delivery of user oriented services is a priority of the project.
NET4 Age-Friendly	ongoing	https://www.net4age.eu/	COST action that aims to establish or expand local or regional ecosystems in each country involved, to work on health and well-being in an age-friendly digital world.
Urbanage	ongoing	www.urbanage.eu	URBANAGE supports the development of age-friendly cities through the roll-out of a new decision-support ecosystem, co-created by relevant stakeholders

			(public servants) and users (older adults). With the help of the decision support ecosystem Digital Twins URBANAGE will tackle the challenge of age-friendly cities and how urban planning needs to be transformed to face an aging society.
City4Age	completed	http://www.city4ageproject.eu/	City4Age aims to activate urban Communities to facilitate the role of social/health services and of families in dealing with mild cognitive impairments and frailty in the elderly population. The challenge is to demonstrate that Cities play a pivotal role in the unobtrusive collection of "more data" on individual behaviours, and with "increased frequency".
NRG2 PEERS	ongoing	https://nrg2peers.com/	NRG2peers aims to set up a platform to gather knowledge, experiences and lessons learned from a set of recent H2020 and Lighthouse projects to ensure the next generation of energy communities to become more a) reliable; b) user-friendly and attractive; c) cost-effective for the customers
domOS	ongoing	www.domos-project.eu	domOS aims to develop and demonstrate an operating system for smart services in buildings. Digitalised buildings will implement a series of smart services, mostly related to energy: (1) energy dashboard for occupants (2) smart control for heating and cooling (3)energy management to integrate buildings into energy grids and markets
interconnect	ongoing	https://interconnectproject.eu/	Interoperable solutions connecting smart homes, buildings and grids. co-creations processes with end-users planned in each demo, design thinking.
BEYOND	ongoing	https://beyond-h2020.eu/	BEYOND offers a Big Data Platform together with a set of technologies allowing energy actors to search, find and utilise buildings' data to design a project & exploit analytics and simulations during the real-time run time of the buildings so as to optimise their operation & energy performance. One of the objective is to provide a sense of security, comply with tenants' well-being and optimizing of indoor comfort conditions.
accept active communities & energy prosumers for the energy transition	ongoing	https://www.accept-project.eu/	"Empowering communities in the energy transition". ACCEPT intends to develop and deliver a digital toolbox, allowing energy communities to offer innovative digital services to reduce the dependency on fossil fuels, save energy in the users households and thus be able to reduce their electricity bill without compromising the quality of living, but ideally increasing the comfort in their homes through smart devices. AI should understand individual or national patterns and continuously adapt technologies to it.