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Development of a rating scale to measuring the KPIs in the generation and evaluation of holistic renovation scenarios

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Abstract. Future building renovation concerns sustainability in broader perspectives facilitated by holistic renovation scenarios. The aim of this paper is firstly identification of both objective and subjective used sustainability sub-criteria and their relevant most effective Key Performance Indicators (KPIs) in building renovation context. It is carried out by adopting a five-stage systematic methodology including review of Danish Standards for the renovation of dwellings. This is a focal point for most – if not all – design team and consultancies interested in renovation projects. Whilst the answer to this is of course very contextual, this paper presents an overview of the sustainability criteria beside their relevant KPIs and how they are perceived and measured by the professional practitioners. To do so, the efforts are put in place towards the development of a rating scale to measuring the sustainability-related measurable KPIs in the generation and evaluation of holistic renovation scenarios for dwellings.

1. Introduction

Today buildings are responsible for 40% of energy consumption and 36% of CO2 emissions in the EU [1]. Most of these buildings will still be in use by the year 2050; reducing their consumption and emissions through renovations is, therefore, a key objective to meet the European Union’s long-term energy and climate goals [2]. Renovation of the existing buildings is receiving ever-increasing attention in many European countries; there is a drive with focus on climatic interests, energy efficiency, environmental impacts, life-cycle cost, indoor climate, spatial quality etc. as a response to the urgent need for significantly more sustainable societies, and the challenges of rapidly increasing urbanization. Existing buildings can benefit from adopting a broader approach to sustainability, which seeks to decrease operation and maintenance costs; reduce environmental impacts; and can increase the building’s adaptability, durability, and resilience towards future challenges. Consequently, buildings may be less costly to operate, may grow in value, last longer, and contribute to a preferable, healthier, more convenient environment to the occupants [3]. When all these interventions are summated, they can move the renovation case towards the goal of overall sustainability, which demands more holistic renovation approaches. The terms sustainable renovation and holistic renovation scenarios in this paper serve to underline a holistic approach where various objectives linking to the sustainability in its full sense are targeted and achieved in a balanced way. Obviously, this is attained by selecting and mixing various types of renovation approaches through the development of holistic renovation scenarios.

Recent investigations into the practice of building renovation reveal different types of challenges and barriers [4], where economic, human behavior, and technical barriers seem to be dominating [5]. There are several reasons for these barriers including variety of the stakeholders and their interests which are involved in the process (i.e. clients, tenants, contractors, municipalities, consultancies etc. – see [6]), a wide range of available renovation options (insulation approaches, window replacement, HVAC
systems etc. - see [7,8]), and broad number of objectives and criteria [or sub-criteria] (e.g. regarding energy efficiency, spatial quality, investment cost etc.) that needs to be addressed [3]. Handling the ‘hard’ objectives and criteria (or measurable criteria such as energy consumption or investment cost) often relies on the use of rational quantitative methods whereas the handling of ‘soft’ objectives and criteria (i.e. identity, spatial, sociality, aesthetic etc.) often requires different methods. The current paper takes offset in the previous research work related to ReVALUE\(^1\) research project on the development of “a hybrid Decision Support Systems – DSS [9]” for the generation of a countless number of holistic renovation scenarios [10]. The DSS has been being developing to be used in the main body of a design methodology named HMSR (Holistic Multi-methodology for Building Renovation) for addressing interactions and trade-offs between renovation objectives and criteria in a holistic manner when generating and evaluating renovation scenarios [11]. The authors discuss the HMSR through a ‘proactive’ integrated design strategy, can help consultancy companies and housing associations, or even municipalities, to deal with the increased complexity and wicked [12] nature of the problem in building renovation [11], for development of holistic renovation scenarios. This two-pronged, mixed-methodology strategy alternates between techno-economic and socio-cultural decision-making to set renovation objectives and criteria as design goals, generate and evaluate a set of renovation alternatives (as renovation scenarios) against these objectives and criteria, and then guides stakeholders in selecting the option that best accommodates their needs. As demonstrated in figure 1, it includes three decision-making levels where a renovation project can primarily be explored, the problem is structured, the scenarios are generated and improved, and ultimately a decision is made at the level 3.

![Figure 1. Overview of decision-making level 1 and 2 in HMSR (adapted from [11])](Image)

The HMSR in the decision level 2, distinguishes between the evaluation of ‘hard’ and ‘soft’ (qualitative) criteria (see ‘b’ and ‘c’ in figure1). Hereafter, as mentioned above, it proposes the application of the hybrid DSS [10] that can be used for generation and evaluation of the holistic renovation scenarios focusing on the ‘hard’ (or measurable) criteria. The hybrid DSS includes a search algorithm with Genetic Algorithms (GA) that is used to combine renovation approaches for generation and evaluation of the simulation-based performance of holistic renovation scenarios. As an initial effort, the focus in the developing hybrid DSS has been on dealing with the three sub-criteria Energy Consumption, Investment Cost, and Thermal Indoor Comfort that all are considered ‘hard’ (or quantitative) in nature and enable us to some extent measure them quantitatively. One way of strengthening such a developing DSS is to review, identify, select, and exploit the most effective quantitative sub-criteria and their related KPIs in the relevant field, which leads in the development of more effective renovation scenarios. The aim in this paper is to identify, describe, and scale the commonly used sustainability-related measurable KPIs, which in the next step can be used within the

\(^1\)http://www.revalue.dk
DSS for the generation and evaluation of a countless number of holistic renovation scenarios in the early design stages of the dwelling renovation projects. This is a focal point for most – if not all – project leaders and companies interested in sustainable renovation field. While the answer to this is of course very contextual, this paper adopts a five-stage research methodology and presents an overview of the experienced drivers with an insight into what measurable KPIs are and how they are perceived and measured by the professional practitioners. As such, the efforts are put in place towards the development of a rating scale to measuring the sustainability-related measurable KPIs in the generation and evaluation of holistic renovation scenarios for dwellings.

The paper is structured with section 2, which summarizes the methodology for developing the results. Section 3 presents an overview of sustainability concept and the existing sustainability assessment methodologies, towards the identification of the sustainability sub-criteria and their measurable KPIs for entire renovation effort. Section 4 gives further detail about the measurable KPIs presenting a description and a five-rating scale that can be used for a proper and systematic evaluation of them over future renovation scenarios. Finally, section 5 provides the conclusion and further research work.

2. Methodology

The research adopts a methodology in two phases to meet its objectives.

2.1. Phase 1: Critical selection of sustainability sub-criteria and their related measurable KPIs

In the development of current research study, it is crucial to choose how the data is employed. It is necessary to outline cohesive and coherent data management systems to a trusted format to assure that the system performance is controlled accurately, which leads the collection of reliable data. The data collection in this paper is related to the identification of existing sustainability KPIs for building renovation [13] and especially in the Danish context. The KPIs can generally be described as a quantifiable measure used to evaluate the success of an organization, product, employee etc. in meeting objectives for performance. The application of KPIs and benchmarking is vital to any improvement strategy. Alwaer et al. [14] argue that an indicator system must present a measure of current performance, a clear statement of what might be achieved concerning future performance targets and a yardstick for measurement of progress along the way. The challenge, in this case, is to identify useful KPIs, requiring a clear conceptual basis [14]. Therefore, the exploration of KPIs will appreciate the accessible data, resources and time, besides the interests and needs of the particular group involved in the identification of KPIs. On the basis of the studies in [14–19], the selected indicators should meet the following criteria:

- Assist in informing choice in design decisions (Representative)
- Be usable by anyone- including professional designers and lay users (Reasonably simple)
- Allow participants to compare and contrast different options
- Be flexible, multipurpose and generic in nature, and useable on many different types of buildings (Sensitive to change).
- Comprehensive: Useable at different phases in a building’s life cycle: concept, design, construction and in use.
- Easy to use, with a simple and clear interface.
- Reflect specific issues that could have impacts on sustainable buildings for current and future developments.
- Be quantifiable and scientifically valid (quantitative criteria or qualitative converted to quantitative).
- Be cost effective but give value.
- Data accessibility should be made easy and not constrain the process.

In order to select the most relevant sub-criteria, the primary stage is to recognize an ‘indicators set’, that acknowledges the building’s performance concerning the local environment, culture and economy,
as well as renovation objectives. In doing so, exploring the relevant KPIs in this paper is made through five stages:

a) An extensive literature review and existing regulations and standards in the Danish context as well as those which are used in connection to the European Union [30-102].

b) A general review of the existing sustainable assessment methodologies and tools (i.e. BREEAM), as well as a meta-synthesis investigation of seven existing sustainability assessment methodologies (e.g. DGNB-DK) used in Danish context [3, 23-35].

c) A review of the building process and currently available performance tools used to evaluate the performance of the buildings, slightly in connection to the design and renovation of the dwellings [11].

d) Surveying relevance key stakeholders and professionals from the relevant disciplines including architects and engineers to review of which indicators are considered most appropriate to renovation projects. The focus group included variety of participants incorporating architects (from architectural consultant companies), contractors, experts (in the field of energy efficiency, indoor comfort, construction & management, civil engineering, health and human well-being), decision-makers, professors and academic board form Department of Engineering-Aarhus University who are associated to ReVALUE project, members of engineering union, and member of government associations (municipality of Aarhus city and Aalborg city located in Denmark).

e) A review of current recommendations for parameters of the indoor environment to develop a common measurement and rating scale for the evaluation of the KPIs [42-52].

2.2. Phase 2: Scales of Measurement – Itemized Rating Scales

For the rating of different parameters concerning the identifying sub-criteria, different itemized rating scales are investigated. Itemized rating scales provide a scale with a number or brief description associated with the category, and the categories are ordered in terms of scale position. Among various used itemized rating scales, Likert and Semantic differential are used commonly [20].

2.2.1. Likert scale

The Likert scale is a measurement scale, where the degree of agreement or disagreement is indicated in terms of a series of statements about stimulus objects [20]. Typically, each scale is divided into five response categories, ranging from ‘strongly disagree’ to ‘strongly agree’. But other odd number leveled items are used often as well, e.g. 7 or 9, because the scale is designed around a neutral point. Each of the statements is assigned a numerical score, ranging either from -2 to +2 or 1 to 5 for the 5-point scale. Likert scales should be symmetrical and thereby include the same number of positive and negative categories. Analysis can be conducted on an item basis or in total by summing across the items [20].

2.2.2. Semantic differential scale

The semantic differential scale is typically divided into 7 points with endpoints associated with bipolar labels [20]. In application, objects are typically rated on many itemized 7-point rating scales, bounded at each end by one of two bipolar statements, ranging from negative to positive. The individual items are scored on a scale ranging from either -3 to +3 or 1 to 7. The resulting data are commonly analyzed with profile analysis. Means or median values on each rating scale are calculated and compared by plotting or through statistical analysis. It helps in determining the overall differences and similarities of the objects [20].

2.2.3. Development of a common measurement and rating scale

Based on the construction of the above scales, here a common scaling system to deal with the evaluation of the KPIs and their measurements in the generation of renovation scenarios is proposed. It is inspired by the Danish Standard 3033 [21]. The Standard in [21] has set up classes for the indoor climate quality, defined by a description of the climate. The classes are divided into 5 classes, all of which are described in table 1. The scale is in alignment with a 5-point Likert scale. The adaption of the parameters into the
categories of the scale is based on the need of the early design phase, which is the ability to evaluate the conditions of the parameters by a few inputs. Class A contains the neutral value, as it holds the minimum requirements according to the Danish Building Regulations [22]. Class A++ represents the really good climate and class C represents the really bad climate.

**Table 1.** Description of the five quality classes in DS 3033 (adopted from [21])

| Class | Description |
|-------|-------------|
| A++   | The really good indoor climate |
| A+    | The good indoor climate |
| A     | Indoor climate corresponding to the Danish Building Regulations |
| B     | Indoor climate less than the minimum requirements in the Danish Building Regulations |
| C     | Indoor climate with a certain risk of negative health effects and significant genes. |

As the scale is built around the minimum requirements in the Danish Building Regulations, the scale shows deviation from the requirements. The Standard illustrates whether an extra effort is made to improve the indoor climate, or if the conditions raise the risk of negative health effect and significant genes. The scale forms a good basis from which to evaluate the environment of the building and is also built around the minimum requirements in the Danish Building Regulation [22]. Therefore, these categories will be used for the evaluation of KPIs and their measurements in this study. However, as an overall judgment might be necessary to be made in the end, therefore, to evaluate the holistic the renovation scenarios, a scoring system must be used instead of letters from A++ to C. Hence, the overall rating can be found evaluating the total score of the scenario performance. To award an improved performance, the highest score is awarded the category that improves the existing conditions the most. For example, class A++ correspond to 5. The description of each category is represented in table 2

**Table 2.** The scores with a the description of the achieved level

| Class | Description |
|-------|-------------|
| 5     | Excellent |
| 4     | Good |
| 3     | Acceptable |
| 2     | Not acceptable |
| 1     | Bad |

By having suggested a standard measurement scale for the environment of buildings, the requirements for each parameter must be adapted to the categories. As requirements differ for different building types, the limits for each parameter must be adapted to these conditions. It is worth noting that many of the KPIs which are particularly represented from standards or regulations can be implemented directly into the scale proposed in table 2 and be awarded a score from 1 to 5.

3. **Sustainability-related KPIs for the generation and evaluation of holistic renovation scenarios**

3.1. **Sustainability**

Sustainability is based on modern information and communication systems [23-26]. There are always unique interests to verify the need for the deep understanding of sustainability as the pattern with the agglomerated set of indicators that are defined by the relevant sub-criteria [27]. As a response to this, today there is a significant range of methods accessible for appraisement of sustainability [28]. They have been expanded beside demands from the surroundings, primarily corresponding to the environment as the main category, where the most recent assessment methodologies attempt to embrace and evaluate
environment, economy and social relations in an equal circumstance [29]. Many of the existing assessment methodologies and tools [29] have been developed for the design of the new buildings, but can be applied to renovation projects as well, and some are mainly intended or adapted for building renovation context. BREEAM [30] (by British Research Establishment), LEED [31] (by US Green Building Council), and DGNB-DK [32] (Danish version of the DGNB [German Sustainable Building Council] tool, developed by Green Building Council Denmark in 2012) are some of the well-known examples of such existing methods. Jensen and Malesa [29] discuss that significant types of such methodologies have a narrow environmental or energy focus. Sustainability has also been being studied and addressed through more holistic perspectives such as the outcome of the research by International Living Future Institute [33] named Living Building Challenge, or the decision support frameworks such as SPeAR by Arup Group Limited Arup [34], or Chris Butters’ sustainability framework [35] in order to represent and evaluate sustainability (as a globally desired design value) in the form of a holistic Value Map.

3.2. Sustainability criteria for the building renovation
In addition to analysis of [30-35] in this paper, as part of the ReVALUE research project, similarly, Jensen et al. [36] investigated a meta-synthesis of 7 existing sustainability assessment methodologies which are used in the Danish context. The studies aimed to compare the methodologies by considering which sustainability criteria they each attach importance to. In this regard, the criteria of each methodology relative to the traditional three-pillar-system of sustainability, including social, environmental, and economic were positioned. Moreover, the process was also considered through specific indicators. The study concludes that the methodologies indeed attach importance to different sustainability criteria, remarking that ‘holism’ in sustainability is a relative term. Even though many of the methodologies are characterized as holistic by the developers e.g. [37,38], not all methodologies address social, economic and environmental sustainability as well as process related issues equally. As such, the models themselves represent a stance on sustainability, which may affect the final design.

While some scholars have argued that sustainability cannot be adequately defined [35], it is agreed that sustainability should be considered not just as another requirement in the design process, but the basis for all design work in building design (or a foundational in building design). Given the many values that sustainability as an umbrella term covers (i.e. energy, pollution, material and water cycles, financial structures, health, land-use, flexibility etc.), researchers and professionals in building design are examining the existing values in building design more closely about stakeholders and pertaining disciplines to cope with the interdisciplinarity of sustainability topics as a societal and cultural value (i.e. socio-diversity, identity, variety, involvement, sociality etc.). This increases the importance of sustainability and extends its coverage even wider related to the ‘soft’ and ‘hard’ values and the existing trade-offs between them. In the light of this, the recent research by Kamari et al. [3] about the development of a new holistic sustainability decision-making support framework, strives to position the holistic sustainability objectives and criteria for building renovation. The study is inspired by some sustainability assessment methodologies [36] using a consensus-based process, via the application of Soft Systems Methodologies - SSM [39] and Value-Focused Thinking [40]. The outcome is a sustainability Value Map for building renovation consisting of three categories – Functionality, Accountability, and Feasibility – with a total of 18 sustainable value-oriented criteria (see figure 2) and 118 sub-criteria. The majority of the criteria in the Functionality category are quantifiable while the qualitative criteria have been listed in Accountability category. From another side, Feasibility category contains a mix of quantitative (i.e. cost criteria) and qualitative criteria such as advantages in using an efficient renovation process by the involvement of the critical stakeholders (especially the building occupants).
3.3. Sustainability sub-criteria and their measurable KPIs for generation and evaluation of holistic renovation scenarios

Table 3 summarizes the outcome of the five-stage analysis including an extensive review of both literature, regulation and standards, and existing assessment methodologies [30-102] employed in this study to identify the sustainability renovation sub-criteria and their measurable KPIs (both objective and subjective) for the generation and evaluation of holistic renovation scenarios in the early design stages of the dwelling renovation projects. In the table, column ‘Source’ refers to the procedure that the KPIs have been identified and subsequently inserted.

| Sub-criteria | KPIs                                                                 | Source                                                                 |
|--------------|----------------------------------------------------------------------|-----------------------------------------------------------------------|
| Indoor thermal comfort [3,13,14,21,22,42,43,47,51,57,60,64,73,84] | Predicted mean vote (PMV)                                      | A x x x                                                               |
| Moisture and mold [3,22,42,43,72] | Predicted Percentage of Dissatisfied (PPD)                        | A x x x                                                               |
| Indoor acoustic comfort [3,13,14,21,22,42,43,48,53,59,61,66,71,80,81,102] | Adaptive approach                                              | A x x x                                                               |
| Indoor lighting comfort | Temperature                                                   | A x x x                                                               |
| Indoor lighting comfort | View, the light transmission of the windows (LT)               | A x x x                                                               |
| Indoor acoustic comfort | Relative Humidity (RH)                                         | A x x x                                                               |
| Indoor acoustic comfort | Dew point temperature                                        | A x x x                                                               |
| Indoor lighting comfort | Daylight access                                               | A x x x                                                               |
| Indoor lighting comfort | View, the light transmission of the windows (LT)               | A x x x                                                               |
| Moisture and mold | Temperature                                                  | A x x x                                                               |
| Category                                      | Indicators                                                                 | Symbols |
|----------------------------------------------|-----------------------------------------------------------------------------|---------|
| Daylight Factor (DF)                         | [3,13,14,21,22,42,43,44,49,63,65,94]                                        | × × ×   |
| Daylight Autonomy (DA)                       |                                                                            | × ×     |
| Spatial Daylight Autonomy (sDA)              |                                                                            | ×       |
| Annual Sunlight Exposure (ASE)               |                                                                            | ×       |
| Unified Glare Rating (UGR)                   |                                                                            | ×       |
| Illuminance                                   |                                                                            | × × ×   |
| Useful Daylight Illuminance (UDI)            |                                                                            | × ×     |
| Luminance                                    |                                                                            | × ×     |
| Indoor air quality (IAQ)                     | [3,13,14,21,22,42,51,56,62,72,74,75,79,90,96,97,98,99,101]                 | Temperature × × 
|                                              |                                                                            | Relative Humidity (RH) × × |
|                                              |                                                                            | Dew point temperature × × |
|                                              |                                                                            | Ventilation rate × × × |
|                                              |                                                                            | Volume (air volume) × × |
|                                              |                                                                            | Ventilation (CO2 concentration level) × × × × |
|                                              |                                                                            | Carbon Monoxide × × × |
|                                              |                                                                            | Radon × × × |
|                                              |                                                                            | Formaldehyde × × × |
|                                              |                                                                            | Airborne Particles × × × |
|                                              |                                                                            | Ultrafine Particles (UFPs) × × × |
|                                              |                                                                            | Volatile organic compounds (VOCs) × × × |
| Energy consumption                           | [3,13,14,22,42,43,45,46,50,51,52,58,67,68,70,82,84,88,89,90,95]            | Total energy demand × × × × |
|                                              |                                                                            | Annual, Energy Use Intensity (EUI) × × |
|                                              |                                                                            | Annual Operating Cost (AOC) × |
|                                              |                                                                            | Energy saving × × × |
|                                              |                                                                            | Renewable Energy Potential × |
|                                              |                                                                            | Annual Carbon Emissions × |
|                                              |                                                                            | Peak Heating / Cooling Load × |
|                                              |                                                                            | Heat transfer coefficient (U-value) × × |
|                                              |                                                                            | Thermal resistance (R-value) × |
|                                              |                                                                            | Shading coefficient × |
|                                              |                                                                            | Solar Heat Gain Coefficient (SHGC) or g-Value × |
| Energy generation                            | [3,22,42,68,82]                                                           | Solar energy generation × |
|                                              |                                                                            | Solar radiation × |
|                                              |                                                                            | Solar insulation × |
| Energy storage                               | [3,70,82]                                                                  | Energy storage × |
| Life Cycle Assessment (LCA)                  | [3,13,14,74,75,90]                                                        | Embodied energy × × × |
|                                              |                                                                            | Carbon emissions balance × |
|                                              |                                                                            | Global warming potential × |
| Water consumption                            | [3,13,14,22,42,69]                                                        | Fixtures × × × |
| Durability                                   | [3,22,42,90]                                                              | Durability × × × |
| Aesthetic                                    | [3,78,85,91,92]                                                           | Intensity of perceivable details × |
|                                              |                                                                            | Density of differentiations × |
|                                              |                                                                            | Curvature of lines and forms × |
|                                              |                                                                            | Intensity of color hue × |
|                                              |                                                                            | Contrast (amongst other color hues) × |
|                                              |                                                                            | Reflectional symmetries on all scales × |
|                                              |                                                                            | Translational and rotational symmetries on all scales × |
|                                              |                                                                            | Degree to which distinct forms have similar shapes × |
|                                              |                                                                            | Degree to which forms are connected geometrically one to another × |
|                                              |                                                                            | Degree to which the colors harmonize × |
| Occupants health                             |                                                                            | Air × × × × |

Note: The symbols × × × indicate the presence of information in the relevant categories.
4. Development of a rating scale to measuring the sustainability-related KPIs in the generation and evaluation of holistic renovation scenarios

Table 3 in the previous section presented a list of 17 sustainability sub-criteria and their 91 related measurable KPIs (both objective and subjective). In the present section, table 4 presents further details about the measurable KPIs (consensus-based selected), where they will be assigned a rating scale from 1-5 in alignment with the proposed rating scale in table 2 (see section 2.2.3). As such there will be two types of KPIs, those that can be calculated on their own that are individually measured for each renovation scenario (i.e. indoor comfort related KPIs), and others that can be measured and used for comparison between various generating renovation scenarios (i.e. cost related KPIs) ahead of evaluating and selecting the most appropriate renovation scenarios.

Table 4. Measurable KPIs for the generation and evaluation of holistic renovation scenarios in the early design stages of the dwelling renovation projects. The column ‘Measurement’ provides information about a common measurement scale from ‘Excellent’ to ‘Bad’ according to table 2. In each cell, the first row refers to ‘Excellent’ and the last row refers to ‘Bad’ (there are five rows in each cell).

| KPIs                                      | Unit | A brief description                                                                 | Value measurement |
|-------------------------------------------|------|-------------------------------------------------------------------------------------|-------------------|
| [3,13,14,22,24,50,55,79,83,93,98,100]     |      |                                      |                   |
| Water                                     |      |                                      |                   |
| Nourishment                                |      |                                      |                   |
| Light                                      |      |                                      | x                 |
| Fitness                                    |      |                                      | x                 |
| Comfort                                    |      |                                      | x                 |
| Mind                                       |      |                                      | x                 |
| Occupants safety [3,22,42,50,90]           |      | Building elements (use of railings)                                                | x                 |
| Fire protection                            |      |                                      | x                 |
| Site safety                                 |      |                                      | x                 |
| Structural safety                          |      |                                      | x                 |
| Electrical safety                          |      |                                      | x                 |
| Sociality [3,41,54,78,85]                  |      | Configuration of the block that affects views (peripheral density and contour)       | x                 |
| The façade harmony between old and newly built/renovated blocks | |                              |                   |
| The height to width ratio (proportion) of internal block spaces (such as courtyards) and the sense of enclosure | |                              |                   |
| Functions in the block, and built and human densities | |                              |                   |
| Outdoor private spaces                     |      |                                      |                   |
| The facade composition and permeability (changes in facade permeability and composition, such as the size of windows and dwelling entrances) | |                              |                   |
| Spatial quality [3,13,14,41,44,54,85]      |      | View out quality                      | x                 |
| Degree of privacy                          |      |                                      | x                 |
| Light                                      |      |                                      | x                 |
| Color                                      |      |                                      |                   |
| Cost (Initial investment cost and annual)  | [3,13,14,22,85,87] | Investment costs                      | x                 |
|                                           |      | Cost efficiency                       | x                 |
|                                           |      | Running costs                         | x                 |
|                                           |      | Life Cycle Cost (LCC)                 | x                 |
|                                           |      | Net Present Value (NPV)               | x                 |
|                                           |      | Internal Rate of Return (IRR)         | x                 |
|                                           |      | Return On Investment (ROI)            | x                 |
Predicted mean vote (PMV) - PMV relates the size thermal comfort factors to each other through heat balance principles. The decisive thermal environmental parameters are: Activity level [met], Clothing insulation [clo], Air temperature [°C], Mean radiant temperature [°C], Relative air velocity [m/s], Relative humidity [%RH].

| PMV | Description |
|-----|-------------|
| -0.2 < PMV < +0.2 | PMV relates the size thermal comfort factors to each other through heat balance principles. |
| -0.5 < PMV < +0.5 | PMV < -0.7; or +0.7 < PMV |
| -0.7 < PMV < +0.7 | PMV < -0.7; or +0.7 < PMV |

Predicted Percentage of Dissatisfied (PPD) - PPD predicts the percentage of occupants that will be dissatisfied with the thermal conditions. It is a function of PMV, given that as PMV moves further from 0, or neutral, PPD increases.

| PPD | Description |
|-----|-------------|
| PPD ≤ 6 | PPD ≤ 6 |
| 6 < PPD ≤ 10 | 10 < PPD ≤ 15 |
| PPD > 15 | PPD > 15 |

Thermal comfort - Adaptive approach - It is recommended in buildings without mechanical ventilation and cooling systems. It is calculated by the operative temperature and the outside temperature with three deviations, defining three comfort classes.

| DHOC | Description |
|-----|-------------|
| DHOC I | 5% DHOC I |
| DHOC II | 5% DHOC II |
| DHOC III | 10% DHOC III |
| > 10% DHOC III | 10% DHOC III |

Reverberation Time (RT) - RT is the time required for the sound to “fade away” or decay in a closed space.

| RT | Description |
|-----|-------------|
| 0.40 ≤ RT ≤ 0.45 | RT ≤ 0.5 |
| RT ≤ 0.6 | RT ≤ 0.9 |
| RT > 0.9 | RT > 0.9 |

Sound Pressure Level (SPL) - SPL is a ratio of the absolute. Sound Pressure and a reference level (usually the threshold of hearing, or the lowest intensity sound that can be heard by most people).

| SPL | Description |
|-----|-------------|
| 45 ≤ SPL ≤ 55 | 40 ≤ SPL ≤ 50 |
| SPL < 40 | SPL < 60 |
| SPL > 70 | SPL > 70 |

Noise Reduction Coefficient (NRC) - NRC is a scalar representation of the amount of sound energy absorbed upon striking a particular surface. An NRC of 0 indicates perfect reflection; an NRC of 1 indicates perfect absorption.

| NRC | Description |
|-----|-------------|
| Context-dependent | Context-dependent |

Daylight access - According to the DBR daylight access here is related to a percentage of the glass area of side lights to the internal net floor area.

| % Glass area / floor area | Description |
|--------------------------|-------------|
| D > 25% | D > 25% |
| 15 ≤ D ≤ 25% | 10 ≤ D ≤ 15% |
| 7 ≤ D < 10% | D < 7% |

Visible Light Transmission of the windows (VLT) - VLT is the percentage of light that is visible through tinted glass. The lower the VLT, the darker the tint, and ultimately the more light that will get blocked.

| % VLT | Description |
|-------|-------------|
| VLT > 0.80 | VLT > 0.75 |
| VLT > 0.60 | VLT > 0.50 |
| VLT > 0.5 | Context-dependent |

Daylight Factor (DF) - DF is a daylight availability metric that expresses as a percentage the amount of daylight available inside a room (on a work plane) compared to the amount of unobstructed daylight available outside under overcast sky conditions.

| % DF | Description |
|------|-------------|
| 4 ≤ DF ≤ 5 | 3 ≤ DF ≤ 4 |
| 1 ≤ DF < 2 | DF ≤ 1 |
| DF > 5 | DF > 5 |

Daylight Autonomy (DA) - DA commonly referred to as ‘dynamic daylight metrics’. It represents as a percentage of annual daytime hours that a given point in space is above a specified illumination level.

| % DA | Description |
|------|-------------|
| DA > 70% | DA > 60% |
| DA > 50% | DA > 40% |
| DA < 40% | DA < 40% |

Spatial Daylight Autonomy (sDA) - sDA describes how much of a space receives sufficient daylight. Specifically, it describes the percentage of floor area that receives a minimum illumination level for a minimum percentage of annual occupied hours.

| % sDA | Description |
|-------|-------------|
| sDA > 75% | sDA > 65% |
| sDA > 55% | sDA > 45% |
| sDA < 45% | Context-dependent |

Annual Sunlight Exposure (ASE) - ASE describes how much of space receives too much direct sunlight, which can cause visual discomfort (glare) or thermal discomfort.

| lux | Description |
|-----|-------------|
| 18 ≤ UGR ≤ 19 | Context-dependent |
| 16 ≤ UGR ≤ 17 | 20 ≤ UGR ≤ 21 |

Unified Glare Rating (UGR) - UGR is a method of calculating glare from luminaires, light through windows and bright light sources.
| **Illuminance** | lux/m² | Illuminance is the total luminous flux incident on a surface, per unit area. | 13 < UGR < 16 | UGR ≤ 13 or 22 ≤ UGR |
|----------------|--------|-----------------------------------------------------------------------|---------------|------------------------|
|                |        | 300 ≤ 1 ≤ 400                                                        |               |                        |
|                |        | 200 ≤ I ≤ 500                                                        |               |                        |
|                |        | 100 ≤ I ≤ 600                                                        |               |                        |
|                |        | I < 100                                                              |               |                        |
|                |        | I > 700                                                              |               |                        |
| **Useful Daylight Illuminance (UDI)** | % | Achieved UDI is defined as the annual occurrence of illuminances across the work plane where all the illuminances are within the range 100-2000 lux. | 90 ≤ UDI ≤ 100 | 80 ≤ UDI ≤ 90 |
|                |        | 70 ≤ UDI ≤ 80                                                        |               |                        |
|                |        | 50 ≤ UDI < 70                                                        |               |                        |
|                |        | 0 ≤ UDI < 50                                                         |               |                        |
| **Luminance** | cd/m²  | Luminance is the measure of the amount of light reflected or emitted from a surface. | 80 ≤ L ≤ 270 | 40 ≤ L ≤ 320 |
|                |        | 30 ≤ L ≤ 370                                                         |               |                        |
|                |        | L < 30                                                               |               |                        |
|                |        | L > 420                                                              |               |                        |
| **Operative Temperature** | °C | Recommended temperature range for summer is 22.8 – 26.1 °C and for winter is 20 – 23.6 °C. Time-dependent |               |               |
| **Relative Humidity (RH)** | % | RH = (actual water vapour density / saturation water vapour density) x 100 | 40 ≤ RH ≤ 60 | 30 ≤ RH ≤ 65 |
|                |        | 20 ≤ RH ≤ 70                                                         |               |                        |
|                |        | RH < 10                                                              |               |                        |
|                |        | RH > 80                                                              |               |                        |
| **Dew point (DP) temperature** | °C | While relative humidity is (as its name suggests) a relative measure of how humid the air is, the dew point temperature is an absolute measure of how much water vapor is in the air. | 15 ≤ DP ≤ 17 | 14 ≤ DP ≤ 18 |
|                |        | 13 ≤ DP ≤ 19                                                         |               |                        |
|                |        | DP < 12                                                              |               |                        |
|                |        | DP > 19                                                              |               |                        |
| **Velocity** | m/s | It relates to movement of sufficient air in a space. Recommended to be 0.25 for indoor environment Context-dependent |               |               |
| **Ventilation rate** | l/s m² | The magnitude of outdoor air flow to a room or building either through the ventilation system or infiltration through the building envelope. | V ≈ 0.5 | V ≈ 0.4 |
|                |        | V ≈ 0.3                                                              |               |                        |
|                |        | V ≈ 0.2                                                              |               |                        |
|                |        | V < 0.2                                                              |               |                        |
| **Volume (air volume)** | cfm/pers | Air volume or flow into an area affects the air change rates or exchange of air between outdoors and indoors. It is recommended 5 cfm/person for residential areas. Context-dependent |               |               |
| **Ventilation (CO₂ concentration level)** | ppm | Dependent on the ventilation flow, the CO₂ concentration reaches a steady state condition in time and thus a certain level of CO₂. As the conditions are dynamic, because people walk in and out of the room, this level will be the maximum CO₂ concentration in the room. CO₂ ≤ 800 |               |               |
|                |        | 800 < CO₂ ≤ 1000                                                     |               |                        |
|                |        | 1000 < CO₂ ≤ 1200                                                   |               |                        |
|                |        | 1200 < CO₂ ≤ 1500                                                   |               |                        |
|                |        | CO₂ > 1500                                                           |               |                        |
| **Radon** | Bq/m³ | Ingress of radon to the indoor climate must be limited by making the structure which is in contact with the subsoil airtight or by using other measures to equal effect. | R ≈ 100 | R ≈ 100 |
|                |        | R ≈ 200                                                              |               |                        |
|                |        | R > 200                                                              |               |                        |
| **Formaldehyde** | mg/m³ | Wood-based sheets or panels, suspended ceilings and other construction products containing substances that emit formaldehyde may only be used if the emission of formaldehyde does not give rise to an unhealthy indoor climate. F ≈ 0.1 |               |               |
|                |        | F ≈ 0.1                                                              |               |                        |
|                |        | F ≈ 0.1                                                              |               |                        |
|                |        | F ≈ 0.2                                                              |               |                        |
|                |        | F > 0.2                                                              |               |                        |
| **Airborne Particles** | mg/m³ | Inhalable particles are typically defined as those with an aerodynamic diameter of 10 micrometers or smaller, commonly referred to as PM10. Less, better |               |               |
| **Ultrafine Particles (UFPs)** | - | UFPs, defined as particles less than 0.1 micrometer diameter, are often produced by combustion and some chemical reactions. Less, better |               |               |
| Volatile organic compounds (VOCs) | - | VOCs are organic chemicals that have a high vapor pressure at ordinary room temperature. Some VOCs are dangerous to human health or cause harm to the environment. | Less, better |
|----------|---|---------------------------------------------------------------------------------------------------------------------------------|-------------|
| Total energy demand OR Annual Energy Use Intensity (EUI) | kWh/m²/year | It is a building’s annual energy use per unit area. Calculations are performed on a monthly basis. It includes calculation of Heating requirements, Cooling requirements, Heat loss from installations, Boilers, Heat pumps, Solar heating, Pumps, Ventilators, Refrigerators, Lighting, Solar cells, Wind turbines, Special components and solutions, Other power consumption for building operations, Process energy | EUI < 20, EUI < 30 + 1000/A, EUI < 52.5 + 1650/A, EUI < 70 + 2200/A |
| Annual Operating Cost (AOC) | m²/year | The annual utility costs incurred for operating a building (electricity + fuel + water). | Less, better |
| Energy saving | kWh/m²/year | Energy saving encompasses amount of the current existing building energy consumption minus amount of the energy consumption after renovation | More, better |
| Energy labeling for the windows (E<sub>ref</sub>) | - | The energy labeling system for windows is based upon the value-size of E<sub>ref</sub>. The benefit of the energy labeling system is that it makes it easier for non-experts to assess energy efficiency between different products. | 0 ≤ E<sub>ref</sub> < 17, -17 ≤ E<sub>ref</sub> < -33, -33 ≤ E<sub>ref</sub> < -55, -55 ≤ E<sub>ref</sub> < -60, -60 ≤ E<sub>ref</sub> < ∞ |
| Renewable Energy Potential | kWh/m²/year | It analyzes all roof surfaces for their estimated potential to generate electricity using photovoltaic (PV or solar electric) panels. | More, better |
| Peak Heating / Cooling Load | m²/ton | A heating or cooling load is the amount of heat that needs to be added to or removed from space to maintain the desired temperature. | Less, better |
| Heat transfer coefficient (U-value) | W/m²K | U-value is the rate of transfer of heat (in watts) through one square meter of a structure, divided by the difference in temperature across the structure. DBR recommendation: - External walls and basement walls in contact with the soil: 0.18 - Partition walls and suspended upper floors adjoining rooms/spaces that are unheated or heated to a temperature, which is 5 °C higher or lower than the temperature in the room concerned: 0.4 - Ground slabs, basement floors in contact with the soil and suspended upper floors above open air or a ventilated crawl space: 0.1 - Ceiling and roof structures, including jamb walls, flat roofs and sloping walls directly adjoining the roof: 0.12 - Doors/gates: 1.8 - Hatches, new secondary windows and skylight domes: 1.4 - Renovated secondary windows: 1.65 | Less, better |
| Thermal resistance (R-value) | m²K/W | R-value is a heat property and a measurement of a temperature difference by which an object or material resists heat flow. | More, better |
| Line of loss (Ѱ) or (psi value) | W/mK | It is equivalent to heat loss through 1 m of the building part. Only external, basement and foundation walls and joints around windows and doors are considered as line losses for independent building components. DBR recommendations: - Foundations: 0.12 - Joint between external wall, windows or external doors and hatches: 0.03 - Joint between roof structure and roof lights or skylight domes: 0.1 | Less, better |
**Shading coefficient** - It can be used to describe the amount of solar heat that passes through a transparent or translucent material compared to the amount of solar heat that passes through a sheet of clear float glass with a total solar heat gain coefficient of 0.87 (i.e. a sheet of clear float glass 3 mm thick which has a shading coefficient of 1).

**Solar Heat Gain Coefficient (SHGC) or g-Value** - these both represent the fraction of incident solar radiation transmitted by a window, expressed as a number between 1 and 0, where 1 indicates the maximum possible solar heat gain, and zero, no solar heat gain.

**Solar energy generation** kWh - To get the most from the solar panels they should ideally be facing south and placed at a 30°-50° angle.

**Solar radiation** kW/m² - Solar radiation is the input for all solar energy generation systems. Measuring solar irradiance provides knowledge to make important decisions on future energy yield, -efficiency, performance and maintenance – crucial factors for investments.

**Solar insulation** kWh/m²/day - The solar insulation is the total amount of solar energy received at a particular location during a specified time period.

**Energy storage** kWh - Energy storage technologies are used to achieve electric power systems of higher reliability and to contribute to the broader use of renewable energy.

**Embodied energy** mj/kg or mj/m² - Embodied energy is the total energy required for the extraction, processing, manufacture and delivery of building materials to the building site.

**Carbon emissions balance (CO2e)** kgCO2e - CO2e balance is the CO2e saved over the life cycle of the building. \( \text{LCO2b} = \text{OCO2s} - \text{ECO2} + \text{MCO2} + \text{DCO2} \)

- \( \text{LCO2b} \) is the carbon emissions balance (kgCO2e)
- \( \text{OCO2s} \) is the carbon emissions saved over the operational phase due to the use of the design strategy (kgCO2e)
- \( \text{ECO2} \) is the carbon emissions embodied in the design strategy (kgCO2e)
- \( \text{MCO2} \) is the energy associated with the design strategy over the maintenance phase (kgCO2e)
- \( \text{DCO2} \) is the carbon emissions associated with the design strategy over the demolition phase (kgCO2e)

**Global warming potential** ratio within a lifetime (years) - GWP is a relative measure of how much heat a greenhouse gas traps in the atmosphere. Common calculating gases in building industry are: Carbon dioxide (CO₂), Methane (CH₄), Nitrous Oxide (N₂O). GWP is calculated over a specific time interval, commonly 20, 100, or 500 years. GWP is expressed as a factor of carbon dioxide (whose GWP is standardized to 1).

**Water consumption - Fixtures** uses/day /person - It is reducing the consumption of potable water for sanitary use in buildings from all sources through the use of water efficient components and water recycling systems.

**Durability** year - It is the ability of a physical product to remain functional, without requiring excessive maintenance or repair, when faced with the challenges of normal operation over its design lifetime. DBR recommended:

- Retrofitted insulation to building elements 40
- Windows with secondary windows and coupled frames 30
- Heating systems, radiators and underfloor heating, and ventilation ducts and fittings including insulation 30
- Heat appliances etc., e.g. boilers, heat pumps, solar heating systems, ventilation units 20
- Lighting fittings 15
- Automation for heating and climatic control equipment 15
- Joint sealing works 10
**Investment costs**

The amount of money spent on the investment.

Investment cost = Material + Labour + Additional + Margins + Taxes

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**Cost efficiency**

DKK/(kWh/m²) year

It is based on the investment cost, lifetime and saved energy for each technical solution.

Cost efficiency = (Investment cost/Lifetime)/Saved energy

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**Running costs**

DKK

The running costs of a business are the amount of money that is regularly spent on things such as salaries, heating, lighting, and rent.

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**Life Cycle Cost (LCC)**

DKK

LCC takes into account all costs of acquiring, owning, and disposing of a building or building system.

LCC analysis is especially useful when project alternatives that fulfill the same performance requirements but differ concerning initial costs and operating costs, have to be compared in order to select the one that maximizes net savings.

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**Net Present Value (NPV)**

NPV is the difference between the present value of cash inflows and the present value of cash outflows over a period of time:

NPV > 0: investment would add value to the firm; the project may be accepted
NPV < 0: investment would subtract value from the firm; the project may be rejected
NPV = 0: investment would neither gain nor lose value for the firm

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**Internal Rate of Return (IRR)**

% of all cash flows from a particular project equal to zero.

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**Return On Investment (ROI)**

% ROI measures the amount of return on investment, relative to the investment’s cost.

ROI = (Gain from Investment - Cost of Investment) / Cost of Investment * 100

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5. Discussion and Conclusion

This paper presented a result of application of a five-stage research methodology to identify, describe, and scale the commonly used sustainability-related measurable KPIs, which in the next step can be used within development of a DSS or renovation domain model (e.g. see [86]) for the generation and evaluation of holistic renovation scenarios in the early design stages of the dwelling renovation projects. The rating scale was developed through a mix of 1-5 Likert scale and semantic differential scale. The proposed rating scale can be used for the evaluation and comparision of the developing renovation scenarios and facilitates the decision-making process for the selection of the most appropriate scenarios.

When generating scenarios for sustainable renovation projects, drivers for sustainable design development must be identified and prioritized in the initial ideation stage of the renovation projects. This entails considering the stakeholders’ priorities and the actual condition of the existing building in the early design stages. In this way, the application of an integrating design methodology which can address the trade-offs between the ‘hard’ and ‘soft’ sustainability criteria (such as the work in [103]) is highly demanded, towards making informed decisions.

Significant work remains to be fulfilled to get the measurement less complex, less subjective, more reliable and the process of calculation more flexible and easier to follow. Moreover, greater integration across various stakeholders, municipal policy makers, planners, and designers need to generate a consensus in the identification and use of numerous existing KPIs. This entails surveying of even bigger group than this study. In addition, considering the broader range of KPIs cannot avoid employing qualitative metrics, the transition to a desirable combination and the simultaneous processing of semantic and numerical variables, or quantitative and qualitative KPIs, ensures a significant and effective evaluation. There is an immense potential for research work in the future concerning the
development and establishment of a sustainable building standardized basis for national and international building policies.

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