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Dwelling renovation and spatial quality The impact of the dwelling renovation on spatial quality determinants

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Abstract

Renovation of dwellings for energy efficiency has further implications other than only technical and economic dimensions, such as performance and cost reduction. This paper demonstrates how the renovation of dwellings for energy efficiency impacts spatial quality by crossing technical measures of dwelling renovation with the definition of spatial quality proposed in Acre and Wyckmans (2014). The results of this crossing are developed further into a spatial quality assessment. Spatial quality consists of the interaction between four determinants: (1) views, (2) internal spatiality and spatial arrangements, (3) transition between public and private spaces, and (4) perceived, built and human densities (Acre and Wyckmans, 2014). There are two main challenges in this work: first to demonstrate that energy renovation of dwellings affects spatial quality and second, to create a clear and generic way to indicate and assess this effect that also allows comparability between before and after renovation. The current state of the art in building renovation emphasizes technical performance and efficiency, costs and user responses to technology. However, there is a facet that is hardly explored in the current literature, which is how building renovation affects spatial quality.

This paper contributes both to the theory and practice in building renovation. First it emphasizes the relevance of non-technical dimensions such as spatial quality and of the need for a cross-disciplinary approach in energy renovation of dwellings. Second, the paper indicates that energy renovation indeed affects spatial quality in dwellings. The main contribution to practice that this article aims to bring forward consists of the spatial quality assessment for dwelling renovation. The technical measures of energy renovation for the building components of floors, internal and external walls, roofs, windows, mechanical services and controls, built area and the use of renewable energy options are considered in this study in relation to their impact on spatial quality. The aim is to identify and strengthen the connection between energy renovation and people's well-being through spatial quality. The inattention to the potential of non-technical dimensions such as spatial quality, by stakeholders involved in the energy renovation of dwellings, constitutes a lost opportunity to increase occupants' receptiveness to energy renovation. This receptiveness can be extended by strengthening the connection between renovation of dwellings for energy efficiency and benefits to occupants' well-being. This work follows the current European tendency of fostering energy deep renovation to reach Europe's 2050 aspirations (BPIE, 2011). Deep renovation is an ambitious building renovation strategy that encourages high energy savings measures and the whole building approach (BPIE, 2013). The paper is intended to benefit design professionals, and building owners such as individuals, corporate entities, public sector or real estate portfolio holders,

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because it points out underlying relations between energy renovation and spatial quality that are often not clearly considered in the renovation of dwellings.

Keywords: Spatial quality assessment; Dwelling renovation; Energy efficiency; Whole building approach; Existing residential buildings

1. Introduction

The paper explores the interaction between two components of sustainable development: dwelling renovation for energy efficiency and spatial quality. A spatial quality assessment is developed to assess the impact of energy renovation on spatial quality in dwellings. The goal is to contribute to connecting the benefits of energy renovation with improvements in people's well-being by improving spatial quality. This work is an answer to European incentives to deep renovation. Deep renovation consist of a strategy that aims to reduce energy demand and fossil fuel import dependency by high levels of energy efficiency achieved in the renovation of building stocks (Bettgenhäuser et al., 2014). Most of the actual renovations achieve around 20–30% of energy savings while deep renovations aim to make savings of at least 60% (BPIE, 2013). This strategy has a holistic approach in which the measures are interdependent and may affect the whole building and its context instead of only punctual interventions. Deep renovation is among the actions to reach Europe's 2050 aspirations (BPIE, 2011).

The article is organised in three main parts. First, the article starts by briefly introducing the spatial quality definition (Acre and Wyckmans, 2014) and presenting the assessment for the analysis of the impact of energy renovation in spatial quality. Second, current technical measures of building renovation for the diverse building components (Baker, 2009; Burton, 2012) are presented and their impact on spatial quality is analysed per building component. The questions to be answered here are whether spatial quality is affected by energy renovation and whether spatial quality concerns influence energy renovation in dwellings. Third, the results of the impacts' analysis are summarised and the framework for the spatial quality analysis is consolidated.

This paper indicates that dwellings renovation (technical dimension) considerably affects spatial quality (non-technical dimension). Therefore this work explores the potential of spatial quality to bridge technical and non-technical dimensions. The paper proposes that spatial quality can be an argument to increase stakeholders' openness towards energy renovation of dwellings because it has the potential to increase people's well-being.

Spatial quality is a complex concept to define due to the widespread definition of the both 'space' and 'quality'. However, Acre and Wyckmans (2014) found similarities among several authors in the definition of spatial quality for dwellings. A range of common determining factors for spatial quality was identified in the research literature: view, privacy, lighting, spatiality, spatial arrangements, the transition between public and private spaces, and perceived, built, and human densities.

There is a general awareness of the relevance of non-technical drivers such as organizational, social and behavioural issues, and of the need for a cross-disciplinary approach (Burton, 2012, Schweber & Leiringer, 2012, Patterson, 2012; ZenN, 2012, and Tweed, 2013). Schweber and Leiringer (2012) point out an increase in the number of publications on the topic of non-technical dimensions from 2003 to 2010. However the tendency is to concentrate research on occupant's behaviour, satisfaction, thermal comfort, and the users' potential to influence energy consumption and CO_2 emissions (Tweed, 2013). Schweber and Leiringer (2012) use the example of the social dimension of design that is primarily considered relating to thermal comfort, to argue that the limitation of the scope might be a consequence of the complexity of adopting a cross-disciplinary approach. The weak point of a primarily technical approach in dwellings renovation is that it emphasises energy efficiency, however many relevant issues remain untouched because they are not directly relevant to energy efficiency improvements (Tweed, 2013). The current challenge to reduce energy consumption and CO_2 emissions is an argument for promoting cooperation among technical and non-technical disciplines and diverse stakeholders.

The result of this work underlines the need for a joint effort among diverse stakeholders involved in dwelling renovation and it proposes a possibility of including non-technical dimensions in dwelling renovation. The spatial quality assessment presented can be particularly relevant to building performance assessment tools. This is because the assessment addresses issues that are not commonly considered in the tools such as spatiality and transition between public and private spaces. However, these issues influence the user's well-being and therefore the acceptance and success of the built environment.

2. Methodology and materials

2.1. Research strategy

The research strategy presents characteristics of two research types, namely the deductive research approach (Delanty and Strydom, 2003), and the correlational research (Groat and Wang, 2013). The deductive approach is characterized by an initial theoretical study, the development of hypotheses from the theory, and the collection and analysis of data to test the hypotheses (Delanty and Strydom, 2003). The hypothesis that energy renovation of dwellings indeed affects spatial quality is developed from prior research and theories on the topics of spatial quality and energy renovation (Acre and Wyckmans, 2014). The hypothesis is tested by analysing data on energy renovation of dwellings and by crossing this data with the spatial quality definition proposed in Acre and Wyckmans (2014). The spatial quality definition is summarized in the spatial quality assessment presented in this paper.

Correlational research is characterized by the attempt to identify 'patterns of relationships' (Groat and Wang, 2013, p. 206) between two or diverse variables. However, the present study does not fit precisely in the correlational research definition by Groat and Wang (2013) because it does not focus on naturally occurring patterns, and it does not use statistics to clarify the patterns of relationships. The focus of the spatial quality assessment proposed is the relationships between spatial quality and energy renovation of dwellings, and the measurement of these relationships. The study presents the relationships between the physical features of space and technical measures in actual energy renovation. These physical features are context dependent and are also likely to affect user acceptation of energy renovation of dwellings (Tweed, 2013).

2.2. Research strategy applied to the study

This study presents an overall assessment to include spatial quality in the scope of energy renovation. There is no obvious relationship between the two elements of the study. However, the study demonstrates that energy renovation indeed affects spatial quality in dwellings. The spatial quality assessment started with the definition of a framework on spatial quality through literature review, considering residential use and the building and block scales (Acre and Wyckmans, 2014). Typical technical measures of renovation of dwellings for energy efficiency in Europe are presented and analysed in this paper. The range of measures considered for this study is a result of both the literature review on energy renovation of dwellings and the analysis of cases of energy renovation of dwellings in Europe. The authors considered for the selection and analysis of technical measures of energy renovation are Baker and Steemers (2002), Giebeler et al. (2009), Burton (2012), Patterson (2012) and Tweed (2013). The technical measures of energy renovation imply changes in the building components of floors, walls, roofs, windows and mechanical services.

The analysis of dwelling renovation cases of the last 10 years indicates that technical measures, primarily intended for the energy renovation of non-domestic buildings, have become commonly used in the renovation of domestic buildings. The use of photovoltaics and the implementation of shading are examples of such measures. Therefore technical measures of energy renovation for non-domestic buildings described by Burton (2012) are included in this study. The cases of energy renovation of dwellings illustrated in the paper are located in Spain, France, Switzerland, Germany and Norway. The examples of existing and new dwellings from the Netherlands and Denmark are used only to illustrate topics related to the spatial quality definition. They do not consist of cases of dwelling renovation.

2.3. Spatial quality assessment and weighting

The impact of energy renovation on spatial quality is illustrated in graphs per building component and it is summarized in the results section of the paper. The departure point of the spatial quality assessment is to make possible the comparison of the impacts on spatial quality both between the diverse technical measures and among the spatial quality determinants. Therefore, each of the four spatial quality determinants is given the same weight of 25% in the total of 100%. The weight of 25% of each determinant is equally divided into its sub-principles and features. Excel© sheets and databases are used to express the relations between energy renovation and spatial quality and to generate the graphs. For example, the reduction or increase of existing glazed areas on facades during the renovation affects the ratio between facade and aperture (doors and windows) areas. The ratio between facade and aperture areas is a feature of facade transparency, which is a sub-determinant of the spatial quality determinant of views. Reduction or increase of existing glazed areas indeed affects facade transparency, therefore the crossing between this technical measure and the spatial quality feature gets its full corresponding score, if not the score would be zero. The values in the graphs only represent this impact (the higher the value, the higher the impact); that is, they do not represent quantities or dimensions. These crossings are performed for the entire assessment in the database, so that it becomes possible to represent graphically the relations between energy renovation and spatial quality. This work consists of the first step on the path to consolidate the spatial quality assessment.

2.4. Spatial quality definition and assessment

The result of the literature study on spatial quality reveals that spatial quality consists of the interrelation between four determinants: (1) views, (2) internal spatiality and spatial arrangements, (3) transition between public and private spaces, and (4) perceived, built and human densities (Acre and Wyckmans, 2014). Three main topics were identified per determinant that can be further developed and combined into a spatial quality assessment. The assessment can be used to both explore design alternatives and to analyse spatial changes before and after dwelling renovation. The authors considered for the definition of spatial quality were Lynch (1960), Chermayeff and Alexander (1966), Rapoport (1971), Alexander et al. (1977/1978), Ashihara (1981), Russell and Snodgrass (1989), Weber (1995), Rapoport (1970), Nasar (1992/2000), Owens (2008), Uytenhaak (2008), Gehl (2010, 2011), and Moulaert (2011).

2.4.1. Spatial quality assessment for views

The three main topics of the spatial quality determinant of (1) view are: (I) view from the inside (private domain) to the outside (public domain) of dwellings and from outside to inside (visual privacy), (II) distances between public and private domains, and (III) view quality (Acre and Wyckmans, 2014). The development of these topics for the spatial quality assessment is indicated in Table 1.

Visibility analyses are part of the assessment in the sub-determinant Depth of Vision (Table 1, item B) and the focus is visual openness and visual privacy. Indraprastha (2012) defines three variables to calculate visual openness: visual distance, transparency ratio and viewing area. Visual distance is the distance between the geometrical centre point p of an enclosed space to the midpoint of the openings (doors and windows) (Fig. 1e). Viewing area is the ratio of viewing area from the geometrical centre point *p* of an enclosed space considering a maximum viewing area of 100° (Fig. 1f) (Pacheco and Wyckmans, 2013).

The assessment of visual privacy (the possibility of being viewed from external spaces) can be performed considering the average value of privacy by distance or the privacy by viewing area. The assessment of privacy by distance

Table 1
Spatial quality assessment for views.

Spatial quality assessment – determinant 1: view (Building and block scales)
(A) Facade transparency
1. Ratio between facade area and apertures (windows and doors) area
2. Ratio between apertures (windows and doors) area and glass surface areas
3. Glazing properties of transmittance and absorptance[a]
(B) Depth of vision
1. Visibility
(a) Percentage of the total number of spaces with view
(b) Visual openness index[b] (Figs. 1e and f)
(c) Visual privacy index[b] (Figs. 1e and f)
2. Quality of the view (composition of the view)[a,c]
(a) Distance of the view (depth) is >6 m (yes or no question)
(b) Width of the view through window(s) is > 28° (yes or no question)
(c) Presence of layers of proximity (sky, landscape and ground) (yes or no question)
3. Internal division of space (configuration of the plan that affects views from inside to outside, and from outside to inside)
(a) Window's length equally to at least half of room depth (d); d $\leq$ 5m, window area (wa) = 1,25 m^2; d > 5 m, wa = 1,50 m^2[c] (yes or no question)
(b) Visual distance (distance between the geometrical centre point *p* of an enclosed space to the midpoint of the openings - doors and windows)[b] (Figs. 1e and f)
(c) Viewing area (ratio between the room and the viewing areas from the geometrical centre point *p* of an enclosed space with a maximum viewing area of 100°)[b] (Figs. 1e and f)
(C) Distance and degree of sight protection (visual privacy and protection of the private domain)
1. View of arriving visitors and entrance, and entry-lock (hall) to the dwelling
(a) Possibility to see arriving visitors (yes or no question)
(b) Possibility to see arriving visitors without being seen (yes or no question)
(c) Entry-lock (hall) area to the dwelling (yes or no question)
2. Availability and configuration of private outdoor spaces
(a) Availability of private outdoor spaces (yes or no question)
(b) Possibility of controlled visual contact with the neighbour's private outdoor spaces (yes or no question)
(c) Availability of private outdoor spaces on the ground floor level (yes or no question)
3. Placement of balconies
(a) Ratio between the transparent (or translucent) and the opaque parts of the handrail
(b) Balcony sticks out or is built into the facade of the building volume
(c) Balconies are on top of each other or staggered
(D) Lighting (access of daylight)[a,c]
1. Daylight access (yes or no question)
2. Daylight factor (DF)
3. Sky view factor (SVF)
(E) Enclosure and peripheral density (configuration of the block that affects views)
1. South/west orientation of the main living areas (yes or no question)
2. Ratio between the height and the width of the enclosed courtyard space
3. Difference between the height of the building and the average height of surrounding buildings (difference in height > than 2/3 of the average height of the surroundings) (yes or no question)

[a] Matusiak (2014).
[b] Indraprastha (2012).
[c] CEN (2014).

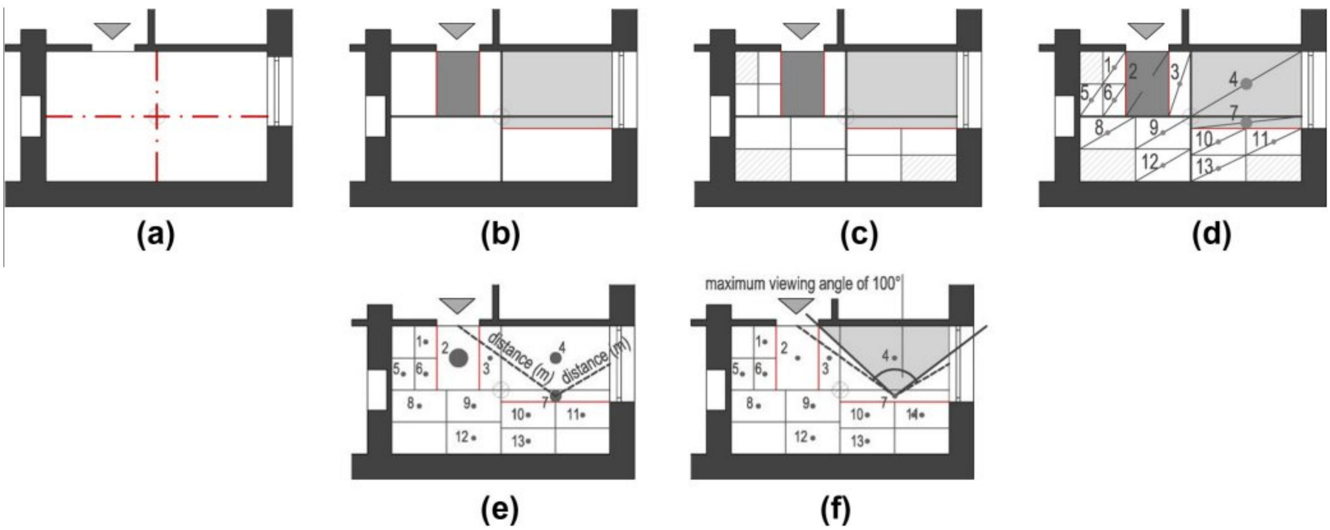

Figure 1. Placement of perceptual centres, (a–d). Distance (m) and maximum viewing angle of 100° between the geometrical centre point 7 of the enclosed space to the midpoint of the openings (e and f) (Indraprastha, 2012). Living room in residential building, Cologne, Germany. © [Detail]. Reproduced by permission of detail.

determines the level of privacy considering the distance from a point p to the opening (Fig. 1e). The assessment of privacy by viewing area considers how many windows and doors are covered by the view angle (Fig. 1f). The more openings covered, the lower the privacy. Indraprastha (2012) summarises the assessment of visual privacy in two indexes: visual privacy index and visual openness index. The visual privacy index indicates that the greater the average distance from a geometrical centre point p to the windows and doors, the higher the visual privacy index. The greater the angle of view at p covering all the windows and doors, the lower is the privacy index. The visual openness index indicates that the greater the average distance from a geometrical centre point p to the windows, the lower the visual openness index. The greater the number of windows covered by the angle of view at p, the greater is the visual openness index (Indraprastha, 2012, in Pacheco and Wyckmans, 2013).

2.4.2. Spatial quality assessment for internal spatiality and spatial arrangements

The second determinant of (2) internal spatiality and spatial arrangements considers the analysis of (I) the articulation between space and its boundaries, and between adjacent spaces, (II) the privacy within the dwelling (zoning considering different groups within the family), and (III) light (access of daylight, layout zoning, and sun orientation of openings) (Acre and Wyckmans, 2014). The development of these three topics for the spatial quality assessment is indicated in Table 2.

The placement of entrances in a room is essential for the centricity and concavity of spaces (Table 2, item A). The graphical manner of finding the perceptual centres of a room is illustrated in Figs. 1a–d (Indraprastha, 2012). The overlap areas between zones of influences within doors (if the room has more than one entrance) and within windows will have a stronger perceptual centrality than the geometric centre of the room (Fig. 2a). Fig. 3a and b consist of the plans of before (a) and after (b) the dwelling renovation; in Fig. 3b the previous four rooms were turned into two rooms connected by a large opening. The presence of overlaps between zones of influences of doors (Figs. 2a, and 3b between the two new rooms), indicates for example that there is no cross circulation in the space, which characterizes spatial efficiency. Spatial efficiency is used here to express the optimization of circulation areas, proportion of space and flexibility to accommodate different uses.

The placement of entrances determines the perception of concavity of the room. The ratio between the Cartesian distance ($x1$) from the door's middle-point, perpendicular to the geometric centre's y axis of the room, and the Cartesian distance ($x2$) from the wall to the geometric centre's y axis of the room indicates the perceived concavity of the room (Figs. 2b, 4a and b). Ratio values closer to 0 indicate high figural concavity.

The concept of passive and non-passive zones is used to calculate the percentage of the floor area that receives the direct benefit of daylight (Baker and Steemers, 1996) (Fig. 2c). The areas outside this zone (the non-passive zones) require artificial lighting. Baker and Steemers (1996) use a passive zone depth from the building envelope to twice the floor to ceiling height. The ratio between the areas in square metres of the passive and non-passive zones indicates the efficiency of the building regarding the access of daylight (Baker and Steemers, 1996).

2.4.3. Spatial quality assessment for transition between public and private spaces

The general main topics of the spatial quality determinant of (3) transition between public and private spaces

Table 2
Spatial quality assessment for internal spatiality and spatial arrangements.

Spatial quality assessment – determinant 2: internal spatiality and spatial arrangements (Building scale)
(A) Centricity and concavity
1. Geometric centre of the space (Fig. 1a)
(a) The relevance of the geometrical centre is weakened (such as consequence of the addition of large openings and enclosing elements)[a] (yes or no question)
(b) Room's shape has only one geometrical centre (figural character, regularity and symmetry) (yes or no question)
(c) Secondary centres are symmetrically arranged (enforcement of the presence of the geometric centre of the room)[b] (yes or no question)
2. Perceptual centres of the space[c] (Figs. 1a–d, 2a, 3a and b)
(a) The space has more than one entrance (yes or no question)
(b) Areas of zones of influence of door(s) overlap (yes or no question) (Fig. 2a)
(c) Areas of zones of influence of window(s) overlap (yes or no question) (Fig. 2a)
3. Placement of entrances (concavity[b]) (Figs. 2b, 4a and b)
(a) Entrance(s) located close to the axes of the room (yes or no question)
(b) Ratio between the Cartesian distance from the door's perpendicular axis to the room's axis (the axis perpendicular to the door), and the Cartesian distance from the wall to the room's axis (Fig. 2b)
(c) Entrance located on the longitudinal axis to increase privacy (yes or no question)
(B) Internal division of space and spatial density
1. Placement of columns and internal walls
(a) Columns standing free in the space (yes or no question)
(b) Spaces defined (subdivided) by columns (yes or no question, if there are free standing columns in the room)
(c) Spaces re-defined (subdivided) by internal walls (changes on the dwelling's plan) (yes or no question)
2. Placement of stairs
(a) Stair is added or replaced (yes or no question)
(b) Free standing stair (detached from space boundaries) (yes or no question, if stair is added or replaced)
(c) Ratio between stair and room areas
3. Ceilings heights
(a) Different heights in the same room (yes or no question)
(b) Spaces defined (subdivided) by different heights (yes or no question, if there are differences in heights in the room)
(c) Minimum height of 2.4 m (yes or no question)
(C) Spatial complexity (spatial hierarchies)
1. Coordinated spatial relationship (spaces with similar dominance)
(a) Areas (in square metres) of adjacent spaces are similar (area difference <30%) (yes or no question)
(b) Direct connection between two or more coordinated spaces (yes or no question)
(c) Coordinated spaces have direct connection with the main circulation (yes or no question)
2. Subordinated spatial relationship (primary and secondary spaces)
(a) Areas (in square metres) of adjacent spaces are significantly dissimilar (area difference >30%) (yes or no question)
(b) Direct connection between two or more subordinated spaces (yes or no question)
(c) Function of the secondary space complements the primary space (yes or no question)
3. Degree of space closure
(a) Ratio between the height and the width of the enclosed space (spaces of permanence)
(b) Room's width is at least the room's height (yes or no question)
(c) Ratio between the width and the length of the enclosed space (spaces of permanence)
(D) Privacy within the dwelling (zoning according to different family group members)
1. Differentiation between social and private zones (yes or no question)
2. Children's domain is directly accessible from the circulation area (yes or no question)
3. Buffer zone between the children's private domain and the parents' private domain (yes or no question)
(E) Lighting[d]
1. Access of daylight
(a) Placement of windows/balcony doors adjacent to side walls (yes or no question)
(b) Placement of windows adjacent to horizontal surfaces (yes or no question)
(c) Ratio between glazing area and indoor surface area (walls, floor and ceiling); and relation between wall thickness and window area
2. Light distribution in the space
(a) Reflectance and absorptance of indoor surface areas
(b) Luminance distribution
(c) Ratio between the daylight (passive) and the non-daylight (non-passive) zones[e] (Fig. 2c)

(*continued on next page*)

Table 2 (*continued*)

Spatial quality assessment – determinant 2: internal spatiality and spatial arrangements
3. Internal zoning of the diverse functions according to orientation (a) Internal zoning considers optimal sun orientation (yes or no question) (b) Minimum of 80% of the floor area of the room is daylit[f] (yes or no question) (c) Direct access of sunlight to living areas[f] (yes or no question)

[a] Von Meiss (2011).
[b] Weber (1995).
[c] Indraprastha (2012).
[d] Matusiak (2006, 2014)
[e] Baker and Steemers (1996/2002).
[f] SBTool (2012).

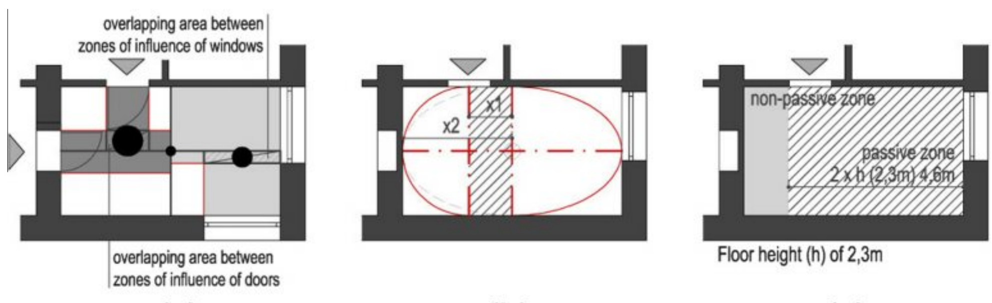

Figure 2. Overlapping zones of influence of doors and windows (a). The placement of entrances and the perception of concavity of the room (b) (Indraprastha, 2012). Passive and non-passive zones (c) (Baker and Steemers, 1996). Living room in residential building, Cologne, Germany. © [detail]. Reproduced by permission of detail.

Figure 3. Placement of perceptual centres: Plans of the first floor before (a) and after (b) the dwelling renovation. Residential building, Cologne, Germany. © [detail]. Reproduced by permission of detail.

are (I) physical barriers between public and private spaces, (II) outdoor private spaces and (III) the facade composition and permeability (changes in facade permeability and composition, such as the size of windows and dwelling entrances) (Acre and Wyckmans, 2014). The development of the main topics for the spatial quality assessment is indicated in Table 3.

Similarity, rhythm and roughness of facade composition are the topics of the sub-determinant of Uniformity and Coherence of Boundaries considered in the spatial quality assessment (Acre and Wyckmans, 2014) (Table 3, item D). In the example below (Figs. 6a and b) symmetry and coherence of the facade composition are achieved in detriment of lighting and ventilation demands. The depth of the

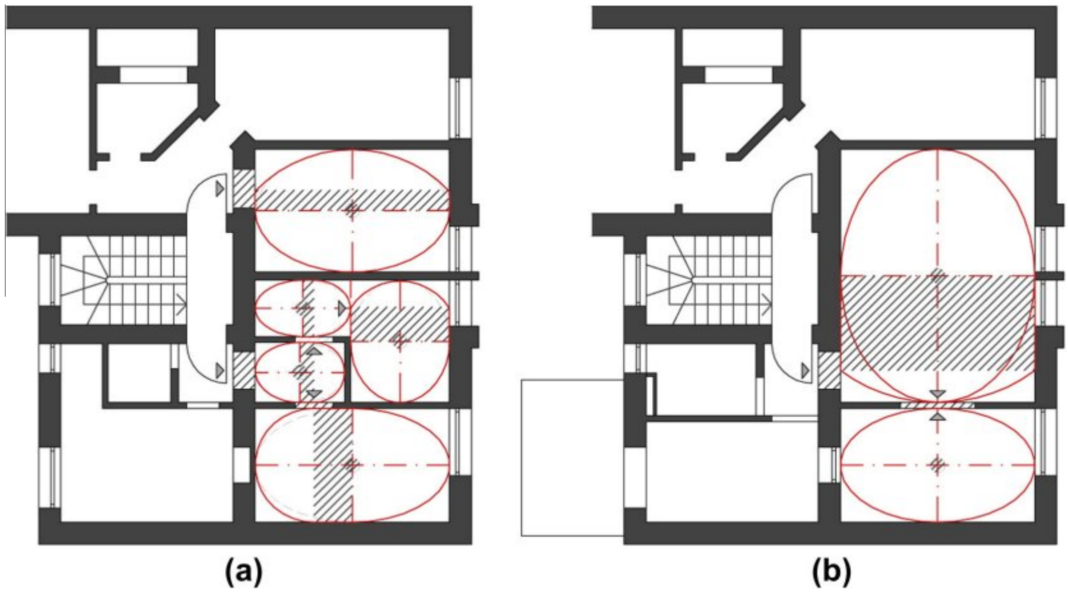

Figure 4. Concavity of the living room in a residential building. Plans of the first floor before (a) and after the dwelling renovation (b). Cologne, Germany. © [detail]. Reproduced by permission of detail.

Figure 5. Clear boundaries between private and semi-public domains (a) (Oslo, Norway), between the semi-public courtyard space and the public space of the street (b) (Breda, The Netherlands), and clear boundaries between private and public domains (c) (Amsterdam, The Netherlands), pictures: Author.

living room is 5 m and the blind wall distance is 2.40 m. In the renovation an extra window is proposed on the blind wall to improve lighting and ventilation in the apartment (Figs. 6c and d).

The impact of changes in the internal division of space on the facade composition is also considered in the assessment (Table 3, item E). Figs. 7a–d illustrate a residential building before and after the energy renovation. Fig. 7b consists of the new plan after the changes in the staircase and elevators' tower. The changes in the internal division of space clearly impact the rhythm and roughness of the facade composition compared to the facade prior to renovation (Figs. 7c and d).

2.4.4. *Spatial quality assessment for perceived, built and human densities*

The fourth spatial quality determinant of (4) perceived, built and human densities considers (I) block physical boundaries (peripheral density and contour), (II) the height to width ratio (proportion) of internal block spaces (such as courtyards) and the sense of enclosure, and (III) functions in the block, and built and human densities (Acre and Wyckmans, 2014). The development of these topics for the spatial quality assessment is indicated in Table 4.

The physical features of the block are the subject of this determinant in the spatial quality assessment. Such features are for example the compactness, porosity and slenderness of the block shape (Figs. 8a and b), and vertical accents and vertical axes of symmetry at the position of the main focus (midpoint of the facade) (Figs. 9a and b).

The relation between the proportions of the block within its boundaries and with its direct surroundings is the maximum scale that the spatial quality assessment reaches. The figure below (Fig. 10) indicates the proportion between heights of blocks and the width of the street in

Table 3
Spatial quality assessment for transition between public and private spaces.

Spatial quality assessment – determinant 3: transition between public and private spaces (Building and block scales)
(A) Private entrance to the dwelling as protected and sheltered standing space (yes or no question)
(B) Clear boundaries between the private, semi-public and public domains (Figs. 5a–c)
1. Clear boundaries within the private and semi-public domains (neighbour to neighbour, tenant to management, interaction dwelling and front yard) (yes or no question)
2. Clear boundaries between private, semi-public and public domains (relation between front yard and street) (yes or no question)
3. Use of materialisation to indicate different domains (yes or no question)
(C) Outdoor private spaces
1. Presence of outdoor private spaces (yes or no question)
2. Outdoor private spaces as effective staying areas (yes or no question)
3. Outdoor private spaces on street level (yes or no question)
(D) Uniformity and coherence of boundaries[a] (single building)
1. Similarity in facade composition
(a) Similarity of architectural elements (similarities in scale and proportion) (yes or no question)
(b) Similarity of facade decoration and materialisation (yes or no question)
(c) Symmetry and coherence of boundaries achieved in detriment of lighting and ventilation demands (yes or no question) (Figs. 6a–d)
2. Rhythm of facade composition
(a) Ordered repetition of architectural elements to achieve an overall unified effect (yes or no question)
(b) Differences of formats and sizes of architectural elements (yes or no question)
(c) Proportion considered in the figure (window) and ground (wall) articulation (yes or no question)
3. Facade roughness[b]
(a) Presence of projected bounces on the facade (such as balconies and bay windows) (yes or no question)
(b) Ratio between the total area of projected bounces and the facade area (facade roughness)
(c) Similarity of materialisation of projected bounces and the facade (yes or no question)
(E) Internal division of space and spatial density and the facade composition (uniformity and coherence of boundaries) before and after intervention
1. Internal division of space impacts similarity of the facade composition (yes or no question)
2. Internal division of space impacts the rhythm of the facade composition (yes or no question)
3. Internal division of space impacts the roughness of the facade composition (yes or no question)

[a] Weber (1995).
[b] Serra (1997).

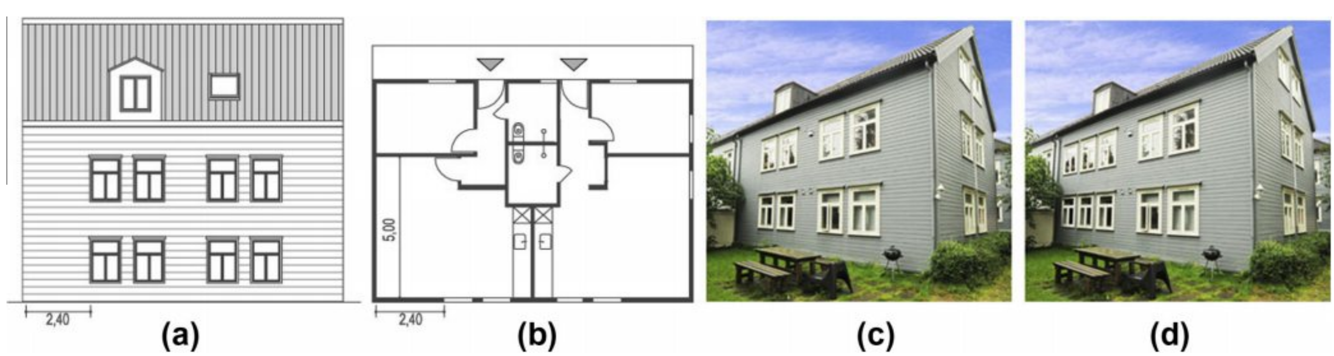

Figure 6. Symmetry and coherence of the facade composition are achieved in detriment of lighting and ventilation demands. Existing facade and plan of residential building (a and b). Existing facade (c) with eight windows and proposal for the addition of two extra windows (d). Trondheim, Norway, pictures: Author.

relation to the 1:1 ratio. This feature is used to analyse the sub-determinant of Enclosure and Peripheral Density (Table 4, item B). Fig. 11a and c illustrate a residential building block before and after renovation. Buildings 'A' are existing buildings and buildings 'B' are additions that close the perimeter of the block affecting its physical and perceived continuities (Fig. 11b) (Table 4, item B).

The analysis of the built space in a quantitative manner is also an essential feature related to spatial quality on the block scale. The measurements of density considered in this study are the floor space index (FSI), the ground space index (GSI) and open space ratio (OSR) (Uytenhaak, 2008). The FSI is the ratio between the sum of the area of all floors and the plot area, and it represents the built density. The GSI is the ratio between the area occupied by the building on the plot and the plot area, and it represents the compactness of the built volume. The ratio between FSI and GSI ($L = FSI/GSI$) indicates the average number of floors. The OSR is the ratio between the plot area excepting the footprint of the building and the sum

Figure 7. (a–d) Changes in the internal division of space due to the dwelling renovation affect the facade composition. Plans (a–b) and facades (c–d) before and after renovation. Residential block, Grenoble, France, pictures: Author.

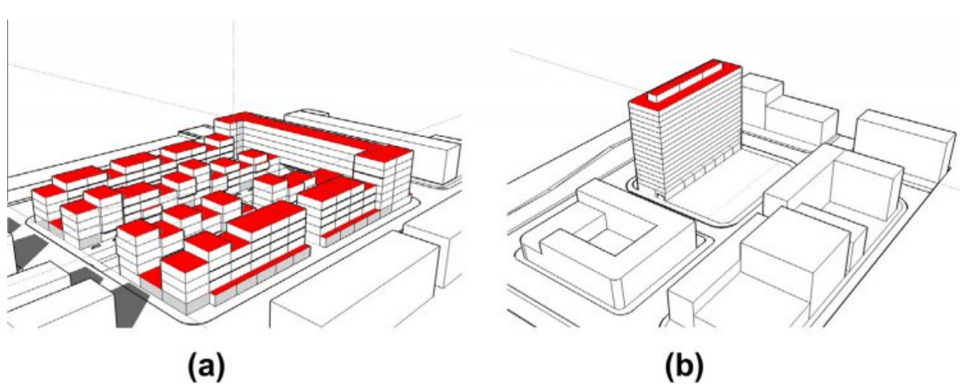

Figure 8. (a) and (b) built density. Compactness, porosity and slenderness of the block shape, pictures: Author.

of the area of all floors. The OSR indicates the openness of the built volume and the pressure on the non-built space of the plot (Uytenhaak, 2008).

These measurements provide a valuable indication about the built space. However, built density is unable to express the whole complexity of spatial quality on the block scale (Acre and Wyckmans, 2014). Therefore they consist of only part of the range of elements (Table 4, item C) for the spatial quality assessment on the block scale (see Figs. 12a–c).

Table 4
Spatial quality assessment for perceived density, built and human densities.

Spatial quality assessment – determinant 4: perceived density, built and human densities (Block scale)
(A) Principle of complexity
1. Surface contrasts[a]
(a) Continuance of edges of the block (quality of continuity) (yes or no question)
(b) Similarity of surface and form of the block's boundaries (yes or no question)
(c) Similarity of facades' composition of the block's boundaries (building materials and use of common signs such as repetitive pattern of windows) (yes or no question)
2. Form simplicity[a,b] (Figs. 8a and b)
(a) Geometry and compactness of the block shape (relation between the external block surface and its volume)
(b) Porosity of the block shape (presence of exterior spaces within the external perimeter of the block such as courtyards) (yes or no question)
(c) Ratio between the area of exterior spaces within the block's perimeter and the area of the block (porosity of the block shape)
3. Dominance[c] (impact of one part over others by means of size and proportion, and interplay between vertical and horizontal) (Figs. 9a and b)
(a) Slenderness of the block shape (relation between the vertical and the horizontal volumes of the block)
(b) Presence of strong vertical accents at the position of the main focus (yes or no question)
(c) Presence of a vertical axis of symmetry at the position of the main focus (perceptual stability) (yes or no question)
(B) Enclosure and peripheral density[c]
1. Height to width ratio of the enclosed space in relation to the 1:1 proportion (relation between the dimensions of the courtyard and the heights of the peripheral buildings)
2. Articulation of space boundaries (contrast between the heights of the peripheral buildings, and proportion between block heights and surrounding blocks in relation to the 1:1 proportion) (Fig. 10)
3. Presence of physical or perceived continuity of space boundaries (perimeter of the block) (yes or no question) (Figs. 11a–c)
(C) Built density[d] (per square metre) (Figs. 12a–c)
1. Floor space index (FSI) and average amount of floors (L = FSI/GSI)
2. Ground space index (GSI)
3. Open space ratio (OSR)
(D) Human density (people per square metre of block area)
1. Percentage of residents of the total users population
2. Percentage of non-residents of the total users population
3. Relation between square metres per person and built area according to functions' demands
(E) Functions (use of the space)
1. Percentage of square metres per function
2. Compatibility of functions within the block (yes or no question)
3. Functions with low human presence located on the ground and first floors (such as parking and storage areas) (yes or no question)

[a] Lynch (1960).
[b] Serra (1997).
[c] Weber (1995).
[d] Uytenhaak (2008).

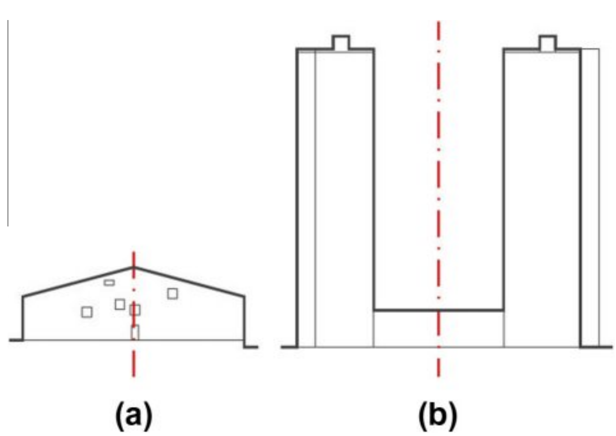

Figure 9. Presence of strong vertical accents and vertical axes of symmetry (indicated by the dashed line). Representation of dwellings, Delft, the Netherlands (a) and Hoge Heren Residential Towers, Rotterdam, the Netherlands (b), pictures: Author.

Figure 10. Proportion between heights of blocks and width of the street in relation to the 1:1 ratio, picture: Author.

2.5. The impact of technical measures for dwelling renovation on spatial quality

Post-occupancy evaluations of buildings are often used to assess the impact of energy renovation on people. However Tweed (2013) indicates that this approach fails to consider the social context properly, because many of the energy efficiency measures and technical issues in energy renovation remain abstract to the occupants. Technology allows the occupants to concentrate on their daily lives while it disappears from the occupants' perception.

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Therefore, occupants often do not clearly see the improvement of energy renovation in their daily lives and well-being: "thus, it can be argued a gap exists in the treatment of socio-technical systems in that they do not address the close interaction between people, spaces and artefacts and the implications these have for energy consumption" (Tweed, 2013, p. 554). Due to the abstract nature of technical issues to occupants such as energy efficiency, non-technical issues, which are clearer to human perception, need to be addressed to improve the interface between technical dimensions and occupants.

Tweed (2013) uses a technical project report by Patterson (2012) of a dwelling renovation realized in 2010 in Newport, south Wales to demonstrate the impact of the changes made to the property as the result of the dwelling renovation. The changes affected the building components of form and space, facade, appliances and mechanical systems. Changes in form and space consisted of the addition of a sun space with roof light that functions as a buffer space for the living room, and a light tube was installed above the stairs to implement natural light. Insulation was applied to the facades and windows were changed to hardwood triple glazed windows. The dwelling got new appliances: a washing machine, a fridge-freezer and a cooker. The changes in mechanical systems consisted of the implementation of a heat pump, a whole-house mechanical ventilation and heat recovery, photovoltaic, solar thermal system located on the roof of the new sun space, the addition of time and temperature controls, low energy light bulbs and removal of the existing gas boiler (Tweed, 2013).

However, after the final visit to the property and interviews with the occupants, Tweed mentions that the dwelling renovation "was valued for the extra space" (the sun space added to the living room) "rather than any thermal benefit" (Tweed, 2013, p. 557). The exclusion of other aspects affected by energy renovation in dwellings such as spatial quality, affects the receptiveness of energy renovation by occupants. There is a contradiction between two facts in the dwelling renovation: first the "rarely discussed" role of energy, which was "not a major concern for the occupants", and second the role of the additional sun space, which "tended to dominate the conversations with the family" (Tweed, 2013, p. 559). Thus, however the relevance of the addition of the sun space, Patterson (2012) mentions the change in space and form as secondary renovation strategies in the technical report.

A spatial quality assessment for dwellings, presented in Section 2 of this article, aims to contribute to connecting the benefits of energy renovation with improvements in people's well-being (Fig. 13). In Sections 2.5.1 to 2.5.8 the paper presents how energy renovation of dwellings affects spatial quality. The impact on spatial quality of technical measures of energy renovation for the building components of floors, internal and external walls, roofs, windows, mechanical services and controls (Baker, 2009; Burton, 2012) are analysed in this study. Changes to the built area of a block (Giebeler et al., 2009) as a consequence of dwelling renovation and the use of renewable energy options are also considered in relation to spatial quality impacts (Baker, 2009).

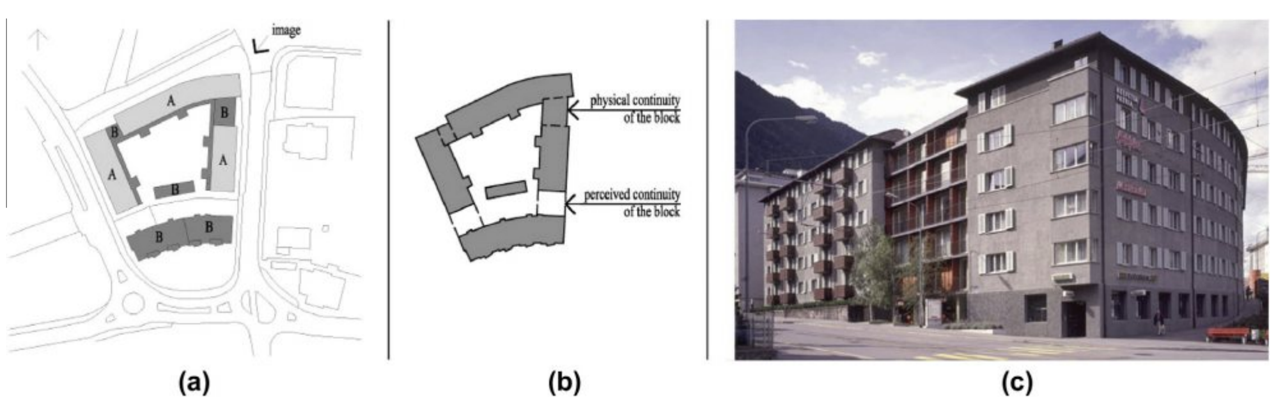

Figure 11. Residential block, Chur, Switzerland. Plan of residential block after renovation (a and b). Buildings "A" are existing; buildings "B" are additions that close the perimeter of the block. © [Detail]. Reproduced by permission of detail. Residential block after renovation with the addition of a new building (c). © [Ralph Feiner]. Reproduced by permission of Dieter Jüngling and Andreas Hagmann.

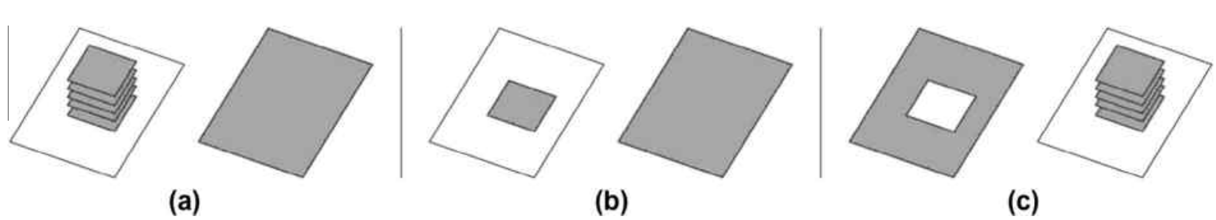

Figure 12. Built density. FSI (a), GSI (b), OSR (c), pictures: Author.

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2.5.1. Building component of floors

The dwelling renovation brings changes in the building component of floors, and these changes affect the spatial quality determinants of (1) view, and (2) internal spatiality and spatial arrangements. Changes in the building component of floors are not relevant for the spatial quality determinants of (3) transition between public and private spaces and (4) perceived density, built and human densities (Graph 1). The changes brought by the renovation consist of adding insulation to the floor with thickness between 125 and 175 mm, and 250 mm for *passivhaus* standard (Burton, 2012) (Appendix 1: 'Description of technical measures and their characteristics for floors', and Table 5).

The crossing between the technical measures for floors and the spatial quality definition indicates the effects of dwelling renovation as follows: changes in the thickness of the floors and therefore ceiling heights, may affect the access of lighting in respect to views (Tables 1 and 5). Regarding the spatial quality determinant of internal spatiality and spatial arrangements (Tables 2 and 5), changes in ceiling heights may affect the spatial quality principles of:

1. (B) *Internal division of space and spatial density.* Changes in ceiling heights may affect the internal division of space because differences in ceiling heights can be used to subdivide spaces without the use of walls (Acre and Wyckmans, 2014; Weber, 1995).
2. (C) *Spatial complexity.* First by indicating spatial hierarchies through differences in ceiling heights and second, by influencing the degree of space closure that is the height to width ratio of the enclosed volume (Acre and Wyckmans, 2014).
3. (E) *Lighting.* Changes in ceiling heights affect the behaviour of the light in the space.

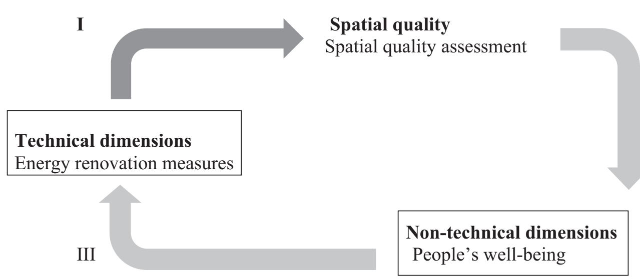
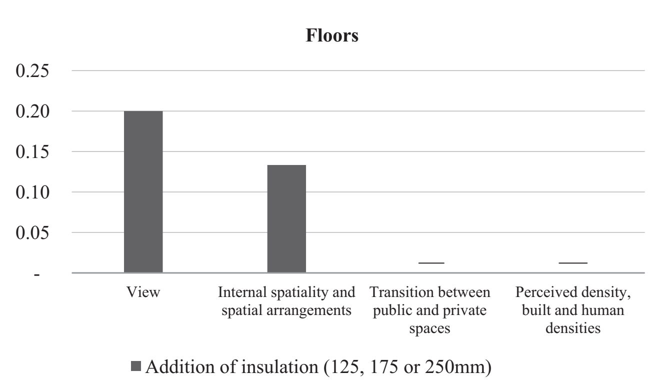


Figure 13. Spatial quality smoothes and strengthens the connection between technical and non-technical dimensions. The present study consists of the arrow 'I' in the figure, the impact of energy renovation on spatial quality in dwellings. Non-technical dimensions are Architectural Values and Cultural Heritage, Stakeholder Awareness and Behaviour, Economic and Ownership Structures, Legislation, Governance and Policy (Karlsson and Lindkvist, 2013). The non-technical driver of spatial quality belongs to the dimension of Architectural Values and Cultural Heritage.



Graph 1. The impact per technical measure of floors' renovation (Baker, 2009; Burton, 2012; Giebeler et al., 2009) on spatial quality.

2.5.2. Building component of external walls

Dwelling renovation brings changes in the building component of external walls, and these changes affect all the four spatial quality determinants (Graph 2). The changes consist of adding insulation with thickness between 80 and 120 mm, and 200 mm for *passivhaus* standard (Burton, 2012) (Appendix 2: 'Description of technical measures and their characteristics for external walls', and Table 6). Balconies are also often added or removed during the renovation. The addition of balconies is meant to improve the plan of the dwelling, whereas the removal is meant to avoid the risk of cold bridges and reduce costs (Burton, 2012; Giebeler et al., 2009). The balcony area can also become an internal area of the apartment during dwelling renovation.

Regarding the spatial quality determinant of (1) view, changes in the thickness of external walls may increase the degree of sight protection, that is, the visual privacy and visual protection of the private domain. For example it can lower the possibility of view of arriving visitors and access spaces. The addition of balconies may lower the degree of visual protection instead, as it increases the percentage of apertures area, thus the facade transparency. However, that will depend on the transparency of the handrail and if the balcony sticks out of the facade or is built into the building volume (Figs. 14a and b). In addition the way balconies are placed at the facade (on top of each other or staggered) affects the degree of visual protection (Uytenhaak, 2008) (Tables 1 and 6).

Changes in the thickness of the external walls through addition of internal insulation affect the spatial quality determinant of (2) internal spatiality and spatial arrangements in two ways (Tables 2 and 6). First, the addition of internal insulation affects the degree of space closure (height to width ratio of the enclosed volume). Second, thicker walls, either as a consequence of the addition of external or internal insulation of 80, 120 or 200 mm (Burton, 2012), influence the access of daylight (Table 6).

The addition of a balcony brings a new entrance to the space. Therefore, it may lead to changes on centricity and concavity, as the placement of the entrance affects the perceptual centres of space (Figs. 2a, 4a and b) (Table 6). The addition or extension of balconies brings new spatial

Table 5
Impact of technical measures for dwelling renovation for floors on the spatial quality determinants.

Floors and spatial quality determinants					
Building refurbishment – dwellings Technical measures		View	Internal spatiality and spatial arrangements	Transition public and private spaces	Perceived, built and human densities
Floors					
Solid concrete ground floors[a]	Insulation applied above existing concrete floors Insulation applied above new concrete floors Insulation applied bellow new concrete floors	Changes on the thickness of the floors and ceiling heights may lead to changes on: D. Lighting (access of daylight)	B. Internal division of space and spatial density (B.3) C. Spatial complexity (C.3a, C.3c) E. Lighting (light behaviour in the space) (E.2c)	No impact is found	No impact is found
Suspended timber ground floors[a]	Insulation applied to the upside of the floor boards Insulation applied to the underside of the floor boards Insulation applied between the joists				
Intermediate floors[b]	Insulation not relevant considering heat losses. However, acoustic insulation might be needed				

[a] Measures described in Burton (2012).
[b] Measures described in Baker (2009).

hierarchy (Acre and Wyckmans, 2014). A balcony is a subordinated (secondary) space connected to the main (primary) space of the room. The primary space retains its figural character, but the boundary to which the secondary space was added becomes more dominant (Weber, 1995) (Figs. 15a and b). The placement of balconies in a room is particularly relevant considering that it can reinforce the main centre when placed symmetrically in relation to it. Addition of balconies to the facade also affects the access of daylight, therefore balcony placements and proportions need to be studied prior to renovation.

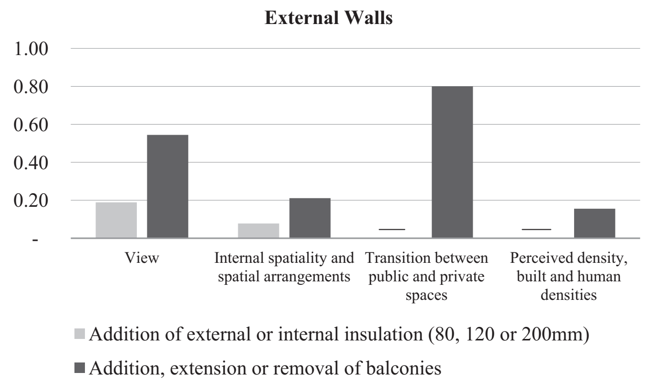
Facades bridge the inside and the outside spaces. Therefore changes in external walls clearly affect the spatial quality determinant of (3) transition between public and private spaces (Tables 3 and 6). Particularly the addition, extension and removal of balconies lead to changes on boundaries between the private and public domains (Table 6). The boundaries within the private, semi-private and semi-public domains consist of the transition within the private space of the dwelling, the semi-private front yard and the semi-public (communal) spaces for accessibility. Thus, these are the relations between neighbour to neighbour (Chermayeff and Alexander, 1966). The boundaries between semi-private, semi-public and public domains consist of the transition between the semi-private front yard, the semi-public (communal) spaces and the public space of the street. These are the relations between resident to neighbourhood (Fig. 16). The addition of balconies creates or increases outdoor private areas of effective staying in a dwelling. Therefore it increases the possibility of controlled social interaction (Alexander et al., 1978; Rapoport, 1971). In addition to the increase in floor area, balconies and loggias function as external insulation and a buffer zone, improving the "energy balance of the compact structure" (Giebeler et al., 2009, p. 234).

The addition, extension or removal of balconies affect the facade composition, thus the uniformity and coherence of boundaries in building and block scales (Table 6). However, formal strategies such as similarity, ordered repetition and articulation between figure (apertures) and ground (facade surface) can bring an "overall unified effect to facade composition" (Weber, 1995, p. 154) (Figs. 17a and b, 18a and b). Changes in the inside space of dwellings may also affect facades such as the need for new openings as a consequence of changes in the subdivision of spaces. Dwelling renovation can also mean interventions on the scale of the block and such interventions can impact the facade composition of a single building. An example is the demolition of a building from a block which frees a facade for the possibility of new openings.

On the other hand changes in the facade composition of a single building can also affect the composition of a block's facade. These changes influence the spatial quality determinant of (4) perceived density, particularly the principle of complexity (Tables 4 and 6) (Acre and Wyckmans, 2014). This principle refers to the surface contrast between diverse building facades according to the quality of steadiness and continuance of edges or surfaces (similarity, analogy, or harmony of surface and form) (Lynch, 1960). The addition, extension or removal of balconies during dwelling renovation also affects built density.

2.5.3. Building component of internal walls

Dwelling renovation often brings changes to the building component of internal walls. The changes consist mainly of the addition and removal of internal walls, and the



Graph 2. The impact per technical measure of external walls' renovation (Baker, 2009; Burton, 2012; Giebeler et al., 2009) on spatial quality.

addition of insulation (Burton, 2012). They affect the spatial quality determinants of (1) view, (2) internal spatiality and spatial arrangements, and (3) transition between public and private spaces. These changes are not relevant for the spatial quality determinant of (4) perceived density, built and human densities (Graph 3). Regarding the spatial quality determinant of (1) view, changes in internal walls affect the visual openness and privacy (Indraprastha, 2012) (Tables 1 and 7). They may also hinder or create the possibility of one-way view to the entrance, to general outdoor spaces and arriving visitors (Fig. 19b) (Acre and Wyckmans, 2014).

The spatial quality determinant of (2) internal spatiality and spatial arrangements is the most affected by changes in the building component of internal walls (Tables 2 and 7). The principle of centricity and concavity is affected since alterations in the internal division of space usually change geometric and perceptual centres, and the placement of entrances (Figs. 1a–d, 2b, 3a and b, 4a and b). Spatial hierarchies may also change since spatial arrangements (coordinated and subordinated spatial relations) vary (Figs. 15a and b, 20a and b). Alterations in the placement of internal walls affect the height to width ratio of the enclosed volume, changing the degree of space closure (Figs. 21a and b).

The privacy within the dwelling itself can change considerably according to the placement of internal walls. Privacy within the dwelling can be significantly improved through zoning, according to different family group members (Chermayeff and Alexander, 1966). Large openings in internal walls can also create new spatial relationships and visually increase the space (Giebeler et al., 2009). Changes in internal walls also affect the access of daylight, which may require revising the internal zoning of the diverse functions according to sun orientation and daylight demands.

Table 6
Impact of technical measures for dwelling renovation for external walls on the spatial quality determinants.

External walls and spatial quality determinants					
Building refurbishment – dwellings Technical measures		View	Internal spatiality and spatial arrangements	Transition public and private spaces	Perceived, built and human densities
External walls					
External walls with external insulation[a]	Wet render system Dry cladding system	Changes on the thickness of the external walls may lead to changes on: B. Depth of vision (B.1b, B.1c, B.2b) C. Distance and degree of sight protection (C.1a, C.1b) D. Lighting	E. Lighting (E.1c) C. Spatial complexity (C.3) E. Lighting (E.1c)	No impact is found	No impact is found
External walls with internal insulation[a]	Laminated insulation board fixed directly to the wall Rigid insulation between battens fixed to the wall Frame with insulation leaving an 30 mm air gap between insulation and the wall Cavity fill for existing brick and block cavity walls				
Addition, extension or removal of balconies risk of cold bridging[a]	Cantilevered balconies can result in serious cold bridges and are difficult to treat. Using insulated windows frames, applying some insulation to reveals, returning insulation along party walls, and insulating any mechanical fixings will overcome this problem	A. Facade transparency B. Depth of vision (B.1, B.3) C. Distance and degree of sight protection (C.2, C.3) D. Lighting	A. Centricity and concavity (A.1a) C. Spatial complexity (C.2) E. Lighting (E.1a, E1c, E.2b, E.2c, E.3b, E.3c)	B. Clear boundaries between the private and public domains C. Outdoor private spaces D. Uniformity and coherence of boundaries E. Internal division of space and facade composition	A. Principle of complexity (A.1c) C. Built density (C.1, C.3)

[a] Measures described in Burton (2012).

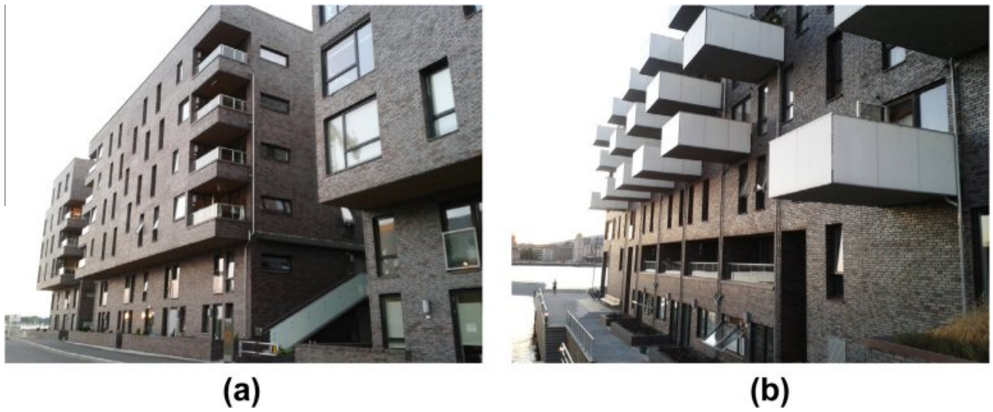


Figure 14. Balconies placed on top of each other (a) and staggered balconies (b). Residential buildings, Oslo, Norway, pictures: Author.

Adjustments to internal walls can lead to variations in facade composition, thus affecting the spatial quality determinant of (3) transition between public and private spaces (Tables 3 and 7). Internal changes in the plan can affect features of facade composition such as uniformity and coherence of boundaries, similarity, rhythm of facade composition, and figure (window) and ground (wall) articulation.

2.5.4. Building component of roofs

The building component of roofs is often affected by dwelling renovation. These changes affect the spatial quality determinants of (2) internal spatiality and spatial arrangements, and (3) transition between public and private spaces. The dwelling renovation measures for roofs considered in this study are not relevant for the spatial quality determinants of (1) view, and (4) perceived density, built and human densities (Graph 4). The renovation measures consist of adding insulation with thickness between 250 and 300 mm, and between 300 and 400 mm for *passivhaus* standard (Burton, 2012) (Appendix 3: 'Description of technical measures and their characteristics for roofs', and Table 8). Measures for the renovation of flat roofs were taken into consideration in this study as well as the implementation of green roofs in dwelling renovation (Table 8).

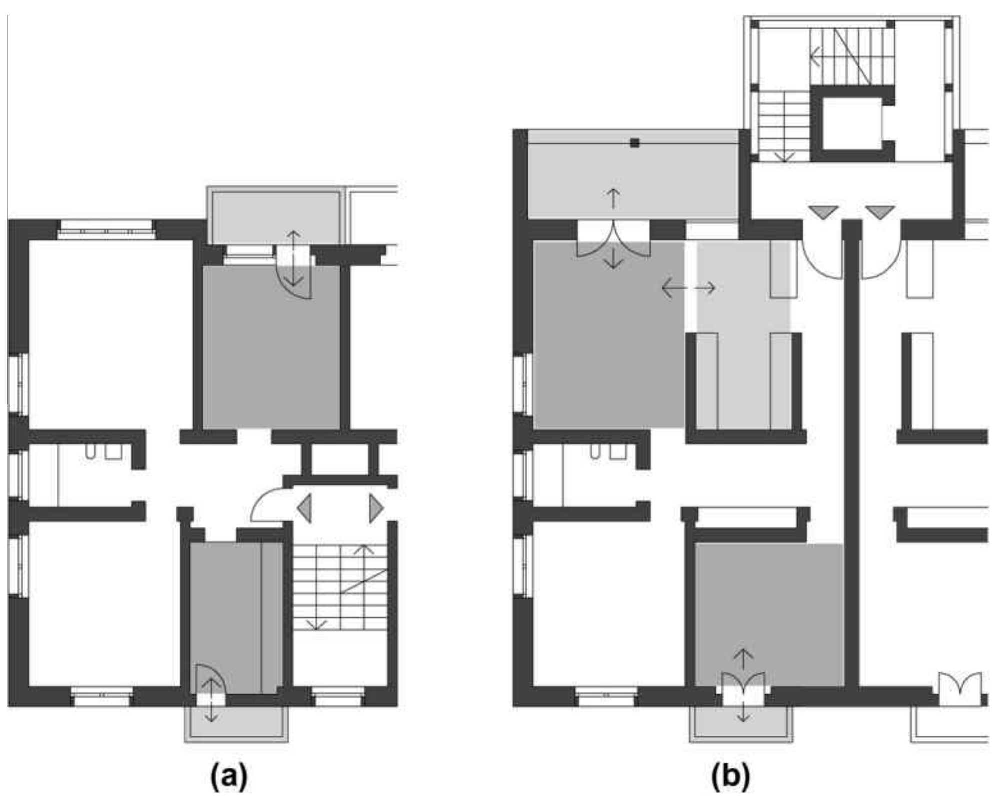


Figure 15. Plans of the first floor before (a) and after (b) the dwelling renovation. Subordinated relationship of spaces. Residential building, Chur, Switzerland. © [Detail]. Reproduced by permission of detail.

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Figure 16. Gradual and physically clear transition between private, semi-public and public domains. Residential building, Amsterdam, the Netherlands, picture: Author.

Two measures are relevant for the spatial quality determinant of (2) internal spatiality and spatial arrangements: the changes in heights and the addition of new green roofs. Changes to ceiling heights may affect the principle of internal division of space and spatial density (Tables 2 and 8). Spaces can be demarcated by differences in height and these differences can be a consequence of the addition of roof insulation. The implementation of green roofs affects spatial hierarchy because the roof area becomes a usable space connected to the dwelling. Therefore the new green roof becomes subjected to spatial relations with the surrounding spaces such as coordinated or subordinated spatial relations (Figs. 15a and b, 20a and b).

The addition of terraced spaces such as flat (green) roofs affects the spatial quality determinant of (3) transition between public and private spaces (Tables 3 and 8). First, because it creates an external usable space and therefore it creates an additional boundary between a private and a public space. Second, the terrace is an outdoor private space that has the potential to be an effective staying area, which promotes social interaction and visual contact among neighbours (Acre and Wyckmans, 2014; Gehl, 2011).

2.5.5. Building component of windows

Dwelling renovation brings changes in the building component of windows and these changes affect all the four spatial quality determinants (Graph 5). The technical measures of dwelling renovation for windows consist of the use of double glazing or triple glazing (for *passivhaus* standard), reduction or increase of framing to improve light and view conditions (Burton, 2012), installation of a secondary glazed screen (second skin), replacement of the glazing and the framing system (Baker, 2009), reduction or increase of existing aperture and glazed area (Burton, 2012), changes in the distribution of glazing by making new apertures to improve daylight distribution, and the implementation of internal or external shading (Baker, 2009) (Appendix 4: 'Description of technical measures and their characteristics for windows', and Table 9).

All the measures mentioned lead to changes in facade transparency in relation to the spatial quality determinant of (1) view, because they affect the aperture's area (windows' and doors' areas). Therefore the ratio between the total wall area and the total aperture area changes (Tables 1 and 9). Facade transparency may also change according to the properties of reflectance, transmittance and absorptance of the new glazing. Measures such as reduction or increase of existing aperture and glazed area (Figs. 22a and b), changes in the distribution of glazing by making new apertures and the implementation of shading, affect the degree of visual protection, that is the visual

Figure 17. (a) and (b) articulation between figure (apertures) and ground (facade surface). Residential building, Amsterdam, The Netherlands, pictures: Author.

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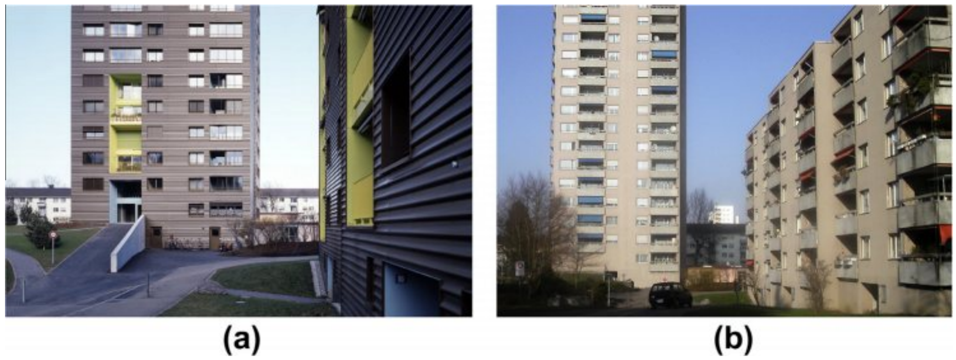
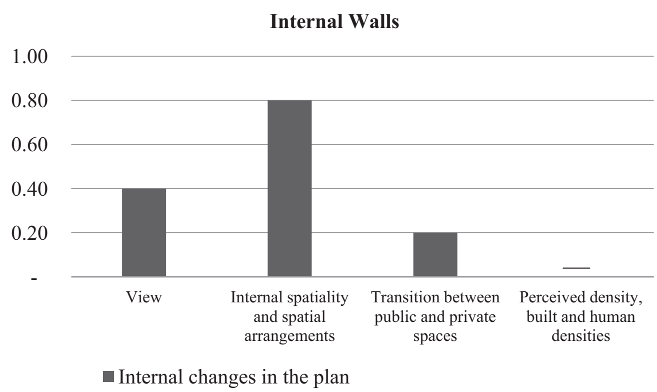


Figure 18. Changes in materialisation of facades and windows' size and composition. Residential blocks, Zürich, Switzerland. Residential block after renovation (a). Residential block before renovation (b).



Graph 3. The impact per technical measure of internal walls' renovation (Baker, 2009; Burton, 2012; Giebeler et al., 2009) on spatial quality.

privacy and protection of the private domain. The one-way view of arriving visitors and access space can be gained or lost with changes in the configuration of apertures, and with the use of shading devices.

The measures considered affect the principles of lighting and spatial complexity in the spatial quality determinant of (2) internal spatiality and spatial arrangements (Tables 2 and 9). The access of daylight varies in quantity and quality of light distribution with changes in size, placement and dimensions of window framing, as well as with the use of shading. The installation of a secondary glazed screen (second skin) can create an internal or external extra space such as a sun space. The addition of an extra space can result in new spatial hierarchies, for example a sun space that functions as a buffer zone to improve energy performance (Giebeler et al., 2009) becomes a subordinated space to the room to which it is connected. The room's figural character remains, while the wall to which the sun space is attached becomes more dominant (Acre and Wyckmans, 2014).

The technical measures of dwelling renovation of reduction or increase of framing, installation of a secondary glazed screen (second skin), reduction or increase of existing aperture and glazed area, (Burton, 2012) and changes in the distribution of glazing by making new apertures (Baker, 2009) affect three principles of the spatial quality determinant of (3) transition between public and private spaces (Tables 3 and 9). First, changes in the size and configuration of windows and the implementation of shading devices affect the facade composition, which is the principle of uniformity and coherence of boundaries. Such changes

Table 7
Impact of technical measures for dwelling renovation for internal walls on the spatial quality determinants.

Internal walls and spatial quality determinants				
Building refurbishment dwellings Technical measures	View	Internal spatiality and spatial arrangements	Transition public and private spaces	Perceived, built and human densities
Internal walls				
Internal changes in the plan[a,b] (insulation not relevant considering heat losses)[a]	Measures can lead to changes on: B. Depth of vision (B.1, B.3) C. Distance and degree of sight protection (C.1) D. Lighting	A. Centricity and concavity (A.1, A.2a, A.2b, A.3) B. Internal division of space and spatial density (B.1, B.2c) C. Spatial complexity D. Sense of privacy E. Lighting (E.2, E.3)	E. Internal division of space and facade composition before and after intervention	No impact is found

[a] Measure described in Burton (2012).
[b] Measure described in Giebeler et al. (2009).

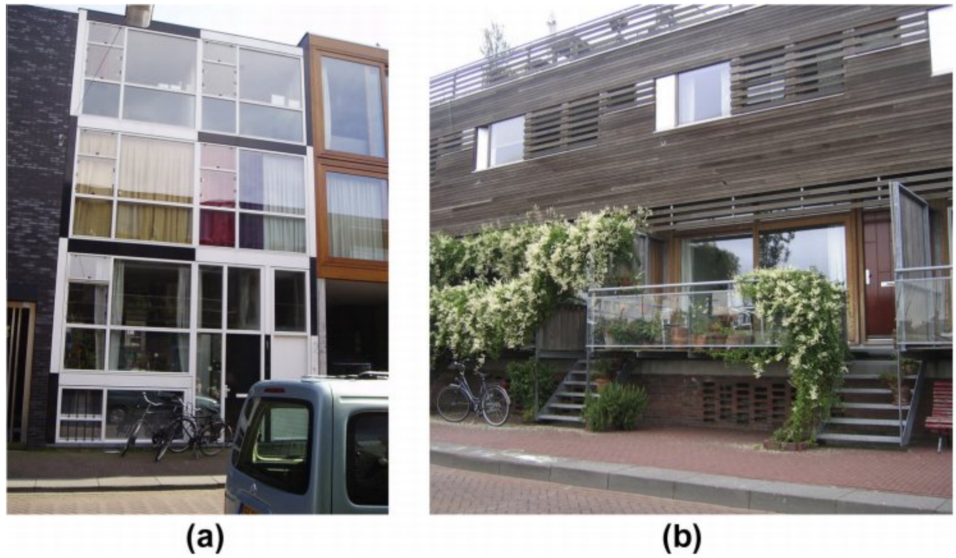


Figure 19. (a) and (b) view of the entrance from inside of the dwelling, and availability of outdoor private spaces. Private dwellings, Borneo, Amsterdam, The Netherlands, pictures: Author.

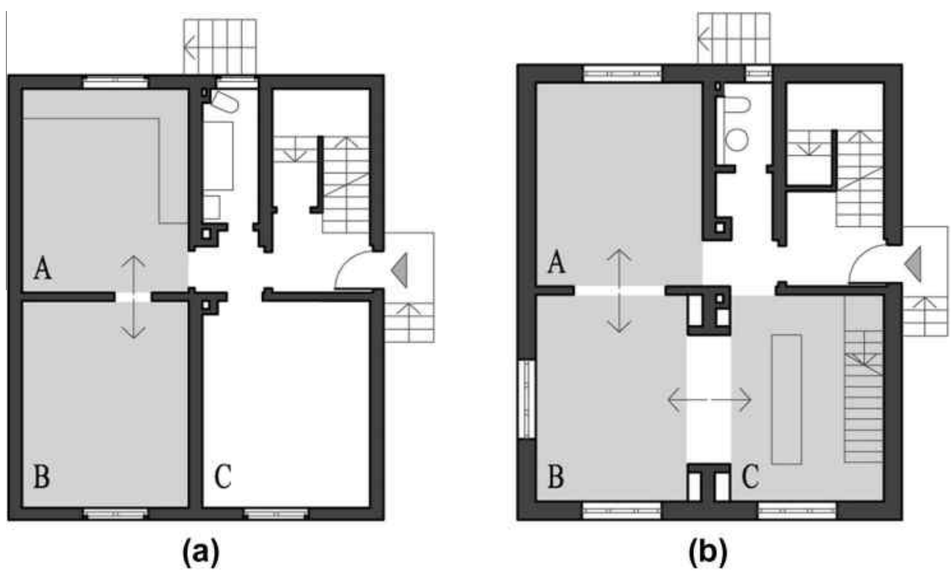


Figure 20. Plans of the ground floor before (a) and after (b) the dwelling renovation. Coordinated relationship of spaces. Private dwelling, Bochum, Germany. © [Detail]. Reproduced by permission of detail.

in facade composition are likely to affect similarities in scale, proportion, facade decoration and materialisation, as well as rhythm of facade composition (ordered repetition to achieve an overall unified effect), and facade roughness (Figs. 23a–c). Similarity in facade composition means similar formats of architectural elements, similarities in scale, proportion and materialisation. Rhythm is the ordered repetition to achieve an overall unified effect. Facade roughness consists of the presence of projected bounces on the facade, such as balconies and bay windows (Serra, 1997).

Second, the measures of installation of a secondary glazed screen or shading (second skin) might bring the addition of outdoor private spaces such as a new balcony resulting from the space between the original house and the new second skin. This new outdoor space can become an effective staying area. Third, the new second skin and the reduction or increase of existing glazed area affect the clarity of the boundaries between public and private domains, for example due to excessive transparency of facades, which may blur the distinction between inside and outside domains.

One principle of the spatial quality determinant of (4) perceived, built and human densities is affected by the changes considered for the building component of windows (Tables 4 and 9). Namely, the principle of complexity for the overall facade composition that is considering the block's facade instead of only the building's facade. The

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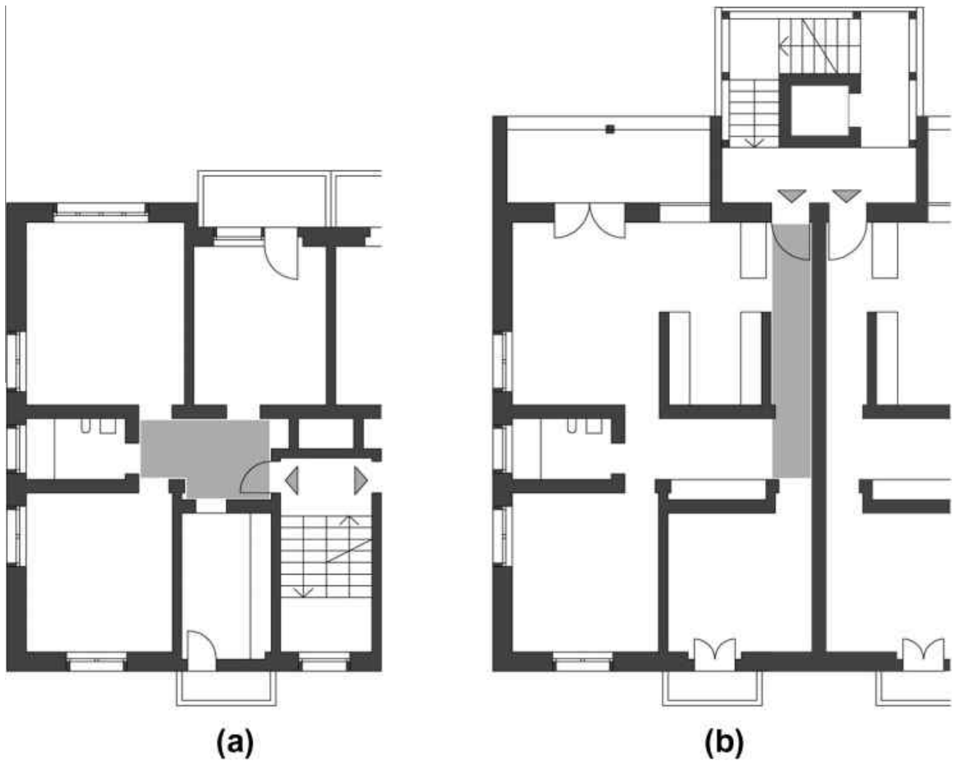
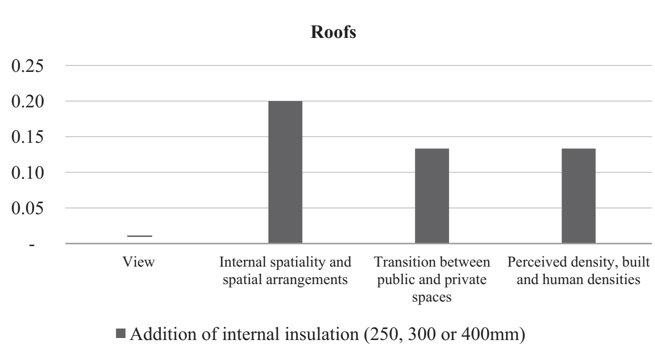


Figure 21. Plans of the first floor before (a) and after (b) the dwelling renovation. Space closure of the hall area. Residential building, Chur, Switzerland. © [Detail]. Reproduced by permission of detail.

complexity of the overall facade composition of the block is affected in terms of surface contrasts, which is the quality of continuity (continuance of edges or surfaces) and the harmony (similarity) of surface and form (building materials and use of common signs such as repetitive pattern of windows) (Lynch, 1960).

2.5.6. Building component of mechanical services and controls

Dwelling renovation in mechanical services and controls affects the four spatial quality determinants (Graph 6). However two measures considered by Burton (2012) are not relevant for spatial quality. The first measure is the improvement of the airtightness of the structure in order to reduce air leakage by repairing mortar joints, filling holes in the external walls, and applying sealant materials to fill gaps around windows, doors and frames. The second measure consists of improvements in the ventilation system such as with the installation of non-visible ducts (Burton, 2012).



Graph 4. The impact per technical measure of roofs' renovation (Baker, 2009; Burton, 2012; Giebeler et al., 2009) on spatial quality.

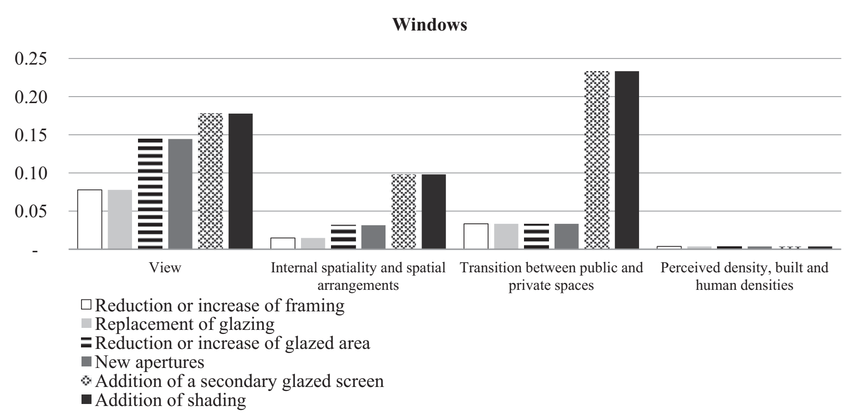
Three of the measures indicated by Burton (2012) are relevant for the spatial quality determinant of (1) view (Tables 1 and 10). The addition of extra south facing windows in order to increase solar gain affects the facade transparency and lighting because it increases the percentage of aperture areas. By contrast, measures to avoid overheating such as the implementation of shading also influence facade transparency and lighting because it decreases the percentage of aperture areas, as well as increasing the degree of sight protection (visual privacy). The addition of vegetation used as shading affects the depth of vision and view's quality (composition of the view).

The spatial quality principle of (2) internal spatiality and spatial arrangements is also affected by the changes considered by Burton (2012) for mechanical services and control. The changes affect two principles of this determinant, namely the spatial complexity and lighting. Spatial complexity is affected because of the space needed to accommodate technical equipment for heating such as solar water systems, gas and boilers, heat pumps and storage cylinders for the provision of domestic hot water (DHW). The space for technical equipment can be a room such as for gas and boilers, heat pumps and storage cylinders as well as height space required to accommodate a ventilation system. The effect on lighting is due to changes in the size of windows

Table 8
Impact of technical measures for dwelling renovation for roofs on the spatial quality determinants.

Roofs and spatial quality determinants					
Building refurbishment – dwellings Technical measures		View	Internal spatiality and spatial arrangements	Transition public and private spaces	Perceived, built and human densities
Roofs					
Roof insulation at ceiling or at rafter levels[a]		No impact is found	Measures can lead to changes on: B. Internal division of space and spatial density (B.3)	No impact is found	No impact is found
Insulation of flat roofs (possibility of adding a terraced private outdoor space)	External roof insulation: Insulation above the roof structure (inverted warm roof system)[a]		No impact is found	C. Outdoor private spaces (C.1, C.2)	C. Built density (C.1, C.3)
	Internal roof insulation: Insulation below the roof structure (cold roof system)[a]		B. Internal division of space and spatial density (B.3)	No impact is found	No impact is found
	Green roofs[b]		C. Spatial complexity (C.1, C.2)	C. Outdoor private spaces (C.1, C.2)	C. Built density (C.1, C.3)

[a] Measures described in Burton (2012).
[b] Measures described in Baker (2009).



Graph 5. The impact per technical measure of windows' renovation (Baker, 2009; Burton, 2012; Giebeler et al., 2009) on spatial quality.

(to increase solar gain and improve natural ventilation), the implementation of shading devices and vegetation (to avoid overheating) (Acre and Wyckmans, 2014).

The measures for mechanical services and control in dwelling renovations that affect the spatial quality principle of (3) transition between public and private spaces are the ones that imply changes in the facade composition (Tables 3 and 10). Changes in the size of windows and the implementation of shading devices affect the facade composition, therefore the principle of uniformity and coherence of boundaries (Figs. 18a and b). The relation between the parts and the whole is the focus of this principle. Changes to the principle of uniformity and coherence of boundaries consist of changes in similarity, rhythm and facade roughness. The addition of vegetation to avoid overheating may affect the principles of clarity on boundaries within private and public domains, and provision of outdoor private spaces. This is because the addition of vegetation may be accompanied by the creation of private outdoor staying areas, and these areas may result in buffer zones in the transition between private and public domains.

The principle of complexity for the overall facade composition is the only principle of the spatial quality determinant of (4) perceived, built and human densities affected by the dwelling renovation measures for mechanical services and control (Tables 4 and 10). The principle of complexity considers the overall facade composition of the block. Changes in the size of windows and the implementation of shading devices are particularly relevant for the principle of complexity. The principle of complexity refers to surface contrasts, which is the quality of continuity, and the harmony of surface and form. This principle focuses on building materials and use of common signs among the building of the same block, for example materialisation and repetitive pattern of windows (Acre and Wyckmans, 2014).

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Table 9
Impact of technical measures for dwelling renovation for windows on the spatial quality determinants.

Windows and spatial quality determinants					
Building refurbishment dwellings Technical measures		View	Internal spatiality and spatial arrangements	Transition public and private spaces	Perceived, built, human densities
Windows					
Reduction or increase of framing to improve light and view conditions[a] Replacement of the glazing and the framing system[b]		Measures can lead to changes on: A. Facade transparency (A.2) B. Depth of vision (B.1) D. Lighting	E. Lighting (E.1c, E.2b, E.3b, E.3c)	D. Uniformity and coherence of boundaries	A. Principle of complexity (A.1c)
Reduction or increase of existing glazed area[a] Changing the distribution of glazing by making new apertures to improve daylight distribution[b]		A. Facade transparency (A.1, A.3) B. Depth of vision C. Distance and degree of sight protection (C.1) D. Lighting	A. Centricity and concavity (A.2) E. Lighting (E.1c, E.2b, E.3b, E.3c)		
Installation of a secondary glazed screen[b] Use of shading[b] (This can result in extra outdoor spaces such as balconies)	Use of external shading Use of internal shading Use of integrated shading	A. Facade transparency (A.1, A.3) B. Depth of vision (B.1, B.2) C. Distance and degree of sight protection D. Lighting	A. Centricity and concavity (A.2a, A.2b, A.2c, A.3) C. Spatial complexity (C.2) E. Lighting (E.1c, E.2b, E.3b, E.3c)	B. Clear boundaries between private and public domains C. Outdoor private spaces D. Uniformity and coherence of boundaries	

[a] Measures described in Burton (2012).
[b] Measures described in Baker (2009).

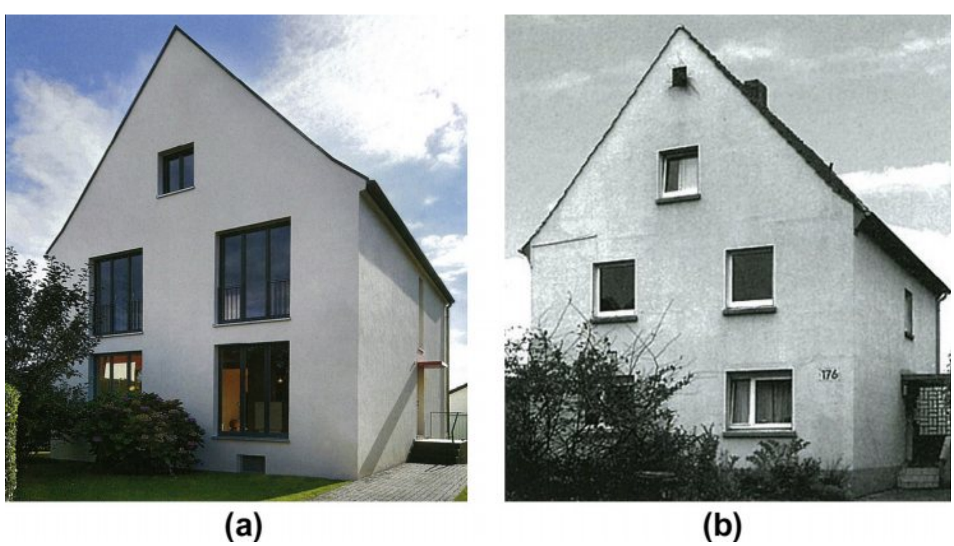

Figure 22. Changes in windows' size, after (a) and before (b) the dwelling renovation. Private dwelling, Bochum, Germany. © [Jörg Hempel]. Reproduced by permission of Jörg Hempel.

2.5.7. Built area

Dwelling renovation may bring changes in the built area of a block by the addition of new buildings and the demolition of existing ones (Giebeler et al., 2009). These changes affect all the four spatial quality determinants (Graph 7). Regarding the spatial quality determinant of (1) view, the changes to built area can affect the principles of depth of vision, distance and degree of sight protection, and enclosure and peripheral density (Tables 1 and 11). The principle of depth of vision implies changes on visibility (spaces with view) and view's quality (composition of the view). The addition or removal of buildings may change the distance and degree of sight protection, that is, visual privacy and protection of the private domain.

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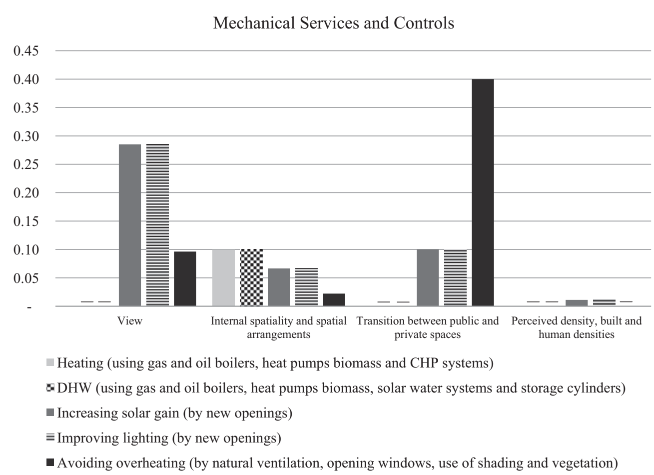
Figure 23. (a–c) Similarities in scale, proportion, materialisation, as well as rhythm and facade roughness. Student housing, Copenhagen, Denmark, pictures: Author.



Graph 6. The impact per technical measure of mechanical services and controls (Baker, 2009; Burton, 2012; Giebeler et al., 2009) on spatial quality.

Alterations in built mass may come with changes in the configuration of outdoor spaces, such as the inclusion or exclusion of private outdoor spaces, which affect the visual interaction between public, collective and private domains (Figs. 24a and b). The last principle of enclosure and peripheral density indicates the configuration of the block (proportion of the block, height to width ratio of the courtyard area) that affects the views from inside spaces to outside spaces, and from outside to inside.

Regarding the spatial quality determinant of (2) internal spatiality and spatial arrangements, the principle of lighting is the only one affected by changes in the built mass on the block scale (Tables 2 and 11). In particular, the access of daylight can be improved or worsened by the addition or removal of buildings in a block. The spatial quality determinant of (3) transition between public and private spaces can be affected by changes in the built mass when these changes affect the configuration of outdoor spaces, such as the inclusion or exclusion of private outdoor spaces (Tables 3 and 11).

The last spatial quality determinant of (4) perceived density, built and human densities is the determinant that is the most affected by changes in the configuration of the block (Tables 4 and 11). The principles of complexity, enclosure and peripheral density, built and human densities and functions undergo the impact of the addition and removal of buildings in a block. The principle of complexity refers to changes in surface contrasts, form simplicity and dominance. Surface contrasts bring up the quality of continuance of edges in facade composition, the nearness of parts (how buildings are clustered) and the harmony (similarity) of surface and form, for example by materialisation and the use of repetitive window patterns (Lynch, 1960, p. 106). The characteristic of form simplicity refers to building geometry, compactness, porosity and slenderness considering all buildings of a block as a whole. The characteristic of dominance refers to the impact of one part (for example a building) over others (the whole block) by means of size and proportion.

The principle of enclosure and peripheral density indicates the configuration of the block. The characteristics which are considered in this principle are height to width ratio of the enclosed space (relation between the dimensions of the courtyard and the heights of the peripheral buildings), articulation of space boundaries (contrast between the heights of the peripheral buildings), and continuity of space boundaries (if there are gaps in the perimeter of the block and how these gaps influence the block contour) (Figs. 11a–c) (Table 4). The addition or removal of buildings in a block clearly impacts both built density (square metre) and human density (people per built square metre). Functions can be added or removed from the block to fulfil new demands (Acre and Wyckmans, 2014). The issues of concern related to functions are the balance between compatible functions such as housing and retail, and the type of functions located on the ground and first floors. Functions located on the ground and first floors are determinants for social control and interaction (Gehl, 2010) (Figs. 25a and b).

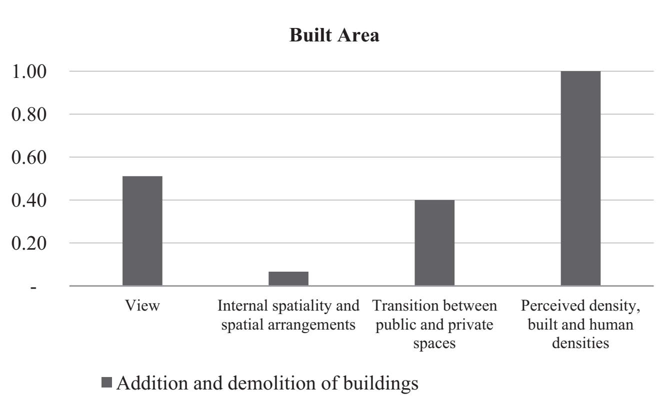
Table 10
Impact of technical measures for dwelling renovation for mechanical services and controls on the spatial quality determinants.

Mechanical services and spatial quality determinants					
Building refurbishment – dwellings Technical measures		View	Internal spatiality and spatial arrangements[c]	Transition between public and private spaces	Perceived density, built, human densities
Mechanical services and controls					
Heating[a]	Efficient space heating Gas and oil boilers, heat pumps, biomass systems and micro CHP systems	No impact is found	Measures can lead to changes on: C. Spatial complexity	No impact is found	No impact is found
Domestic hot water (DHW)[a]	Efficient provision of DHW Solar water systems Gas and boilers, heat pumps and storage cylinders				
Increasing solar gain[a]	New openings: sun entering a dwelling through east, south and west windows, as well as roof lights, assisted by thermal storage in floors and other thermal mass	A. Facade transparency . Depth of vision C. Distance and degree of sight protection (C.1) D. Lighting	E. Lighting (E.1, E.2b, E.2c, E.3b, E.3c)	D. Uniformity and coherence of boundaries	A. Principle of complexity (A.1c)
Lighting installations[b]	New openings: maximise the use of daylight by architectural means in order to minimise artificial lighting energy				
Avoiding overheating[a]	Natural ventilation for cooling through opening windows The use of shading to avoid external heat gains				
	The use of planting and vegetation to avoid external heat gains	B. Depth of vision (B.2a, B.2c) C. Distance and degree of sight protection (C.1a, C.1b) D. Lighting	E. Lighting (E.2b, E.3b, E.3c)	B. Clear boundaries within private and public domains C. Outdoor private spaces as effective staying areas	No impact is found

[a] Measures described in Burton (2012).
[b] Measures described in Baker (2009).
[c] Acre and Wyckmans (2014).

2.5.8. The use of renewable energy options

The implementation of renewable energy options is currently becoming a common practice in dwelling renovations (Burton, 2012). In particular the implementation of photovoltaic devices can affect all the spatial quality determinants (Graph 8 and Table 12). The technical measures that are relevant for the spatial quality determinants are the use of re-cladding panels and roof tiles, and the use of opaque PV as shading devices (Baker, 2009).



Graph 7. The impact of built area (Baker, 2009; Burton, 2012; Giebeler et al., 2009) on spatial quality.

Photovoltaic panels as cladding and shading devices influence the spatial quality determinants of (1) view because they might affect the facade transparency and the degree of sight protection (visual privacy) (Table 1). They may also impact the access of daylight in the spatial quality determinants of (1) view and (2) internal spatiality and spatial arrangements (Tables 1 and 2). The use of cladding and shading devices on facades influences the facade composition such as the features considered in the principle of uniformity and coherence of boundaries (Table 3). These features are similarity, rhythm of facade composition and figure and ground articulation. The changes in facade composition affect the principle of complexity of the spatial quality determinant of (4) perceived, built and human densities. This principle refers to surface contrasts and facade composition on the block scale.

3. Results and discussion

Energy renovation affects spatial quality in dwellings substantially that supports the hypothesis of this study. The hypothesis is confirmed by the analysis of the impact of current technical measures of energy renovation of dwellings on spatial quality. The results suggest the potential of energy renovation in increasing people's well-being

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Table 11
Impact of technical measures for dwelling renovation for building area on the spatial quality determinants.

Built area and spatial quality determinants				
Building refurbishment dwellings Technical measures	View	Internal spatiality and spatial arrangements	Transition between public and private spaces	Perceived density, built and human densities
Built area				
Addition of new buildings and demolition of existing ones[a]	Changes on built area can lead to changes on: B. Depth of vision (B.2a, B.2c) C. Distance and degree of sight protection (C.2.) D. Lighting E. Enclosure and peripheral density (configuration of the block that affects views)	E. Lighting (E.3)	B. Clear boundaries between the private and public domains C. Outdoor private spaces	A. Principle of complexity B. Enclosure and peripheral density C. Built density D. Human density E. Functions

[a] Measures described in Giebeler et al. (2009).

Figure 24. (a) and (b) outdoor private spaces and gradual and physically clear transition between private and semi-public domains. Residential building, Oslo, Norway, pictures: Author.

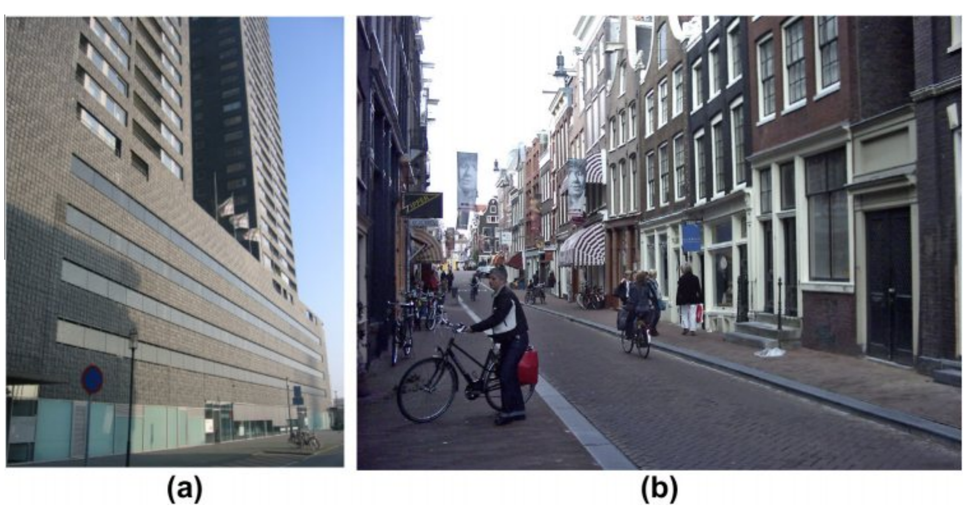
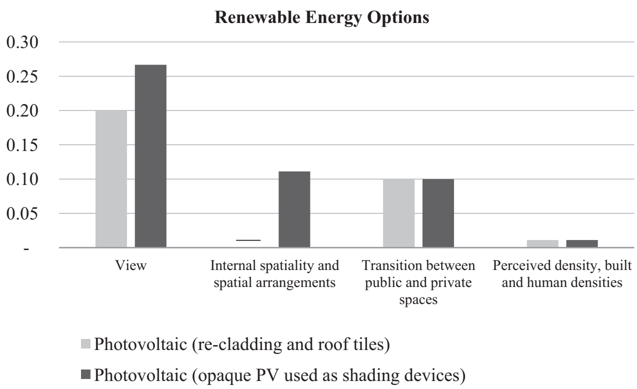


Figure 25. (a) Storage spaces and parking located on the ground and first floors, functions with low human presence, residential building, Rotterdam, the Netherlands. (b) Retail and dwellings, functions with high human presence, Amsterdam, the Netherlands, pictures: Author.

and therefore user acceptation to renovation, through the consideration of the non-technical dimensions of view, privacy, lighting, spatiality, spatial arrangements, the transition between public and private spaces, and perceived, built, and human densities. The results of this work opens up for a whole underlying facet of building



Graph 8. The impact of renewable energy options (Baker, 2009; Burton, 2012; Giebeler et al., 2009) on spatial quality.

renovation that has not been clearly brought to the surface in the current literature and practice. This work considers particularly the whole building approach, which goes beyond punctual interventions in buildings and therefore aligns with the European deep renovation strategy.

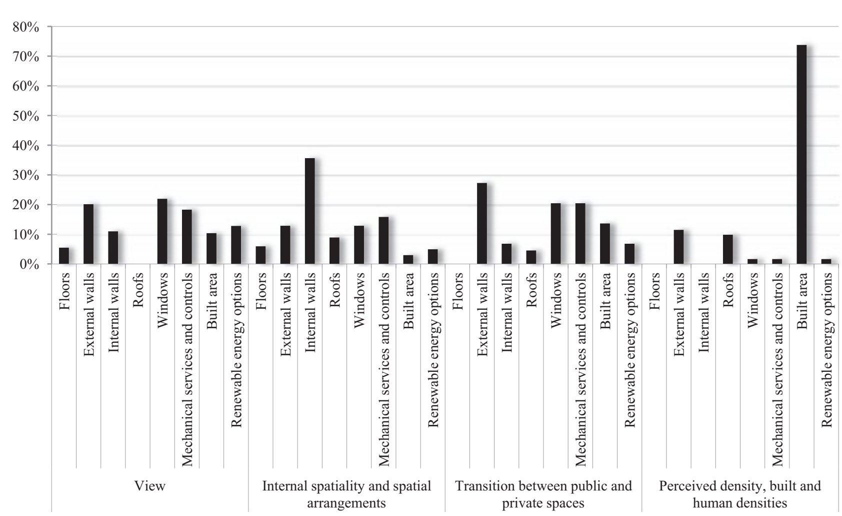
Many of the results were expected, such as the high impact of the renovation of external walls and windows on view and transition between public and private spaces (Graph 9). Also the renovation of internal walls was expected to highly influence the internal spatiality and spatial arrangements. Another expected result was the impact of the addition or demolition of buildings in an urban block on perceived density, built and human densities.

Surprisingly, renovation of mechanical services and control proved to affect the four spatial quality determinants (Graph 9). The reason for this impact indicates a rather positive development for the understanding of energy renovation. Technical equipment for heating, DHW and ventilation requires space to be accommodated. However, measures such as changes in the size of windows to increase solar gain and natural ventilation, the implementation of shading and use of vegetation to avoid overheating, are increasingly being considered as real alternatives in common energy renovation in dwellings both in the literature and in actual practice, instead of primarily the use of technical installations. Changes in the size of windows and the use of shading might be opportunities to

Table 12
Impact of technical measures for dwelling renovation for renewable energy options on the spatial quality determinants.

Renewable energy options and spatial quality determinants				
Building refurbishment – dwellings Technical measures	View	Internal spatiality and spatial arrangements	Transition between public and private spaces	Perceived density, built and human densities
Renewable energy options				
Photovoltaic re-cladding panels and roof tiles[a] Photovoltaic opaque PV used as shading devices[a]	Measures can lead to changes on: A. Facade transparency (A.1) B. Depth of vision (B.1, B.3a) C. Distance and degree of sight protection (C.1a, C.1b, C.2) D. Lighting	E. Lighting (E.1c, E.2b, E.2c, E.3b, E.3c)	D. Uniformity and coherence of boundaries	A. Principle of complexity (A.1c)

[a] Measures described in Baker (2009).



Graph 9. The impact of dwelling renovation (Baker, 2009; Burton, 2012; Giebeler et al., 2009) per building component on the four spatial quality determinants.

improve the facade composition. The use of shading devices and vegetation can offer the possibility to create outdoor staying areas and therefore improve social control and human interaction. This development opens up many possibilities towards sustainable practice in building renovation as well as towards the exploration of building renovation alternatives that focus primarily on the end user rather than on technical and economical concerns.

The spatial quality assessment (Tables 1–4) consists of the other main result of the paper. The assessment enables the comparability between the diverse technical measures related to spatial quality impact, and among the spatial quality determinants. After the analysis of the impact of energy renovation on spatial quality, the weighting initially adopted for each spatial quality determinant (25% per determinant of a total of 100%) remains unchanged. That is, the determinants have the same significance to the analysis of spatial quality; therefore the weighting of the four spatial quality determinants is expected to be the same. This is because the study indicates the real impact of energy renovation on spatial quality. The weighting of the sub-determinants and features (Tables 1–4) might vary according to the renovation case and context. The assessment provides an indication of how user-friendly in terms of spatial quality, the energy renovation can be for a dwelling. The assessment is intended to be used before the renovation, during the plan phase and after the renovation in order to evaluate the improvements and declines in the dwelling regarding spatial quality.

4. Conclusion and further work

The study explores the impact of energy renovation in domestic buildings with the aims of identifying the consequences of the renovation to spatial quality as well as of developing a spatial quality assessment. Energy renovation affects spatial quality in dwellings and its impacts should not be overlooked, mainly considering the actual incentives to the whole building approach of the deep renovation strategy. This study has three key messages to be considered for further work:

1. The study proposes a set of guiding principles that help design professionals and users to integrate spatial quality in energy renovation of dwellings.
2. The spatial quality assessment is context dependent at the same time as it leaves designers, developers, and building owners freedom for designing.
3. This work is carried on considering the actual tendency of energy renovation of dwellings towards non-technical concerns. This tendency is an opportunity that design professionals, building owners, end users and public and private developers should not overlook in the years to come.

The assessment is unlike to be a final product; rather, it is open for further development and improvements. Therefore the next step is to assess cases of dwelling renovation to improve the spatial quality definition and to further develop the assessment. These cases will be assessed preferably during the design phase of the renovation. This is because the design phase is the phase prior to the construction when there are more chances for interventions in the project in comparison to the construction phase. There is a higher potential to improve spatial quality in the dwellings when spatial quality is considered in the early stages of the renovation process.

The results of this study indicate that spatial quality concerns might have influence energy renovation in dwellings and encouraged building owners to undertake energy renovation. These two hypotheses are going to be explored in future work. The evidence of the spatial quality's influence of on energy renovation is that many of the measures taken in energy renovation, which affect spatial quality, are not necessarily related to energy concerns. Examples are the addition of a green roof, internal changes in the plan and the addition or demolition of buildings, though they could potentially be related to energy matters. Green roofs add thermal mass to the roof and therefore they contribute to cooling. Internal changes in the plan can result in a more efficient zoning regarding sun orientation and space use, decreasing the use of artificial lighting and heating. Also the demolition of poorly insulated buildings can lower the energy demands in an urban block. However, these measures that are not directly related to energy issues might have encouraged user's receptiveness towards energy renovation.

Acknowledgements

The authors wish to thank their colleague Barbara Matusiak and the partners of the ZenN Project for their cooperation. The cases of dwelling renovation that will be evaluated using the spatial quality assessment belong to the ZenN project, Nearly Zero Energy Neighbourhoods funded by the European 7th Framework Programme (Grant agreement No.: 314363), Work Package 4 Non-Technical Drivers. The cases are located in the cities of Oslo, Grenoble, Malmö and Eibar. The aim of the ZenN project is to 'demonstrate the advantages and affordability of energy efficiency renovation, and to create the right context to replicate this experience around Europe' (Nearly Zero Energy Neighbourhoods [ZenN], 2012). The goal of the WP4, to which this work is related, is to support the success of energy-efficiency strategies in dwelling renovation by optimising the synergies between technical and non-technical dimensions, to which spatial quality belongs.

Appendices

Appendix 1
Description of technical measures and their characteristics for floors.

Building refurbishment – dwellings		
Technical measures		Technical characteristics
Floors		
Solid concrete ground floors[a]	Insulation applied above existing concrete floors	Insulation on the top of the slab, timber battens at thresholds with metal nosing, vapour-control layer on the insulation, chipboard flooring and floor
	Insulation applied above new concrete floors	Damp-proof membrane, rigid insulation on the top of the slab, chipboard flooring and floor
	Insulation applied bellow new concrete floors	Sand bedding, damp-proof membrane, rigid insulation, concrete floor slab, floor and floor
Suspended timber ground floors[a]	Insulation applied to the upside of the floor boards	Flooring joints sealed, floor, insulation, netting to support insulation, timber joists
	Insulation applied to the underside of the floor boards	Floor, insulation, timber joists, plasterboard in the basement
	Insulation applied between the joists	Floor, insulation between timber joists, plasterboard in the basement
Intermediate floors[b]	Insulation is not relevant	Insulation is not relevant considering heat losses. However, acoustic insulation might be needed

[a] Measures described in Burton (2012).
[b] Measures described in Baker (2009).

Appendix 2
Description of technical measures and their characteristics for external walls.

Building refurbishment – dwellings		
Technical measures		Technical characteristics
External walls		
External solid walls with external insulation[a]	Wet render system	Consists of insulant, fixings, base coat render with glass fibre plastic or metal mesh, and a top-coat render with or without a finish
	Dry cladding system	Consists of supporting framework or cladding fixing system fixed to the wall, ventilated cavity, breather membrane and cladding material. Useful where existing appearances (architectural features) need to be maintained
External solid walls with internal insulation[a]	Laminated insulation board fixed directly to the wall	Plasterboard laminated to insulation board, rigid closed cell insulation fixes with special fastening and adhesive
	Rigid insulation between battens fixed to the wall	Plasterboard, vapour check, rigid or semi-rigid insulation boards between the battens
	Frame with insulation leaving an 30 mm air gap between insulation and the wall	plasterboard, vapour control layer, insulation and 30 mm min air gap
	Cavity fill for existing brick and block cavity walls	insulation injected into the wall cavity
Addition, extension or removal of balconies risk of cold bridging[a]	Cantilevered balconies can result in serious cold bridges and are difficult to treat. Using insulated windows frames, applying some insulation to reveals, returning insulation along party walls, and insulating any mechanical fixings will overcome this problem	Where good insulation levels are applied in a house, uninsulated areas such as window frames and reveals and party walls can become cold bridges and attract condensation when internal humidity is high, which can lead to damp and mould growth

[a] Measures described in Burton (2012).

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Appendix 3
Description of technical measures and their characteristics for roofs.

Building refurbishment – dwellings		
Technical measures		Technical characteristics
Roofs		
Roof insulation at ceiling level[a]		Plasterboard ceiling, insulation between joists, insulation above joists, cables lifted above insulation
Roof insulation at rafter level[a]		Plasterboard ceiling, vapour barrier, insulation between rafters, rigid insulation, 50 mm air gap
Insulation of flat roofs[a]	External roof insulation: Insulation above the roof structure (warm roof system)	Known as warm roof system, in order to avoid interstitial condensation. It consists of vapour check, rigid insulation, waterproof layer with reflective paint
	External roof insulation: Insulation above the roof structure (inverted warm roof system)	Known as inverted warm roof system, in order to avoid interstitial condensation. It consists of water proof layer, rigid insulation, vapour check and structural roofing (gravel or concrete tiles)
	Internal roof insulation: Insulation below the roof structure (cold roof system)	Known as cold roof system, where it is not possible to construct a warm roof system. It consists of insulation applied under the roof structure, vapour barrier and ceiling. External water proof membrane applied on the roof structure
Insulation of flat roofs[b]	Green roofs	Green roofs add thermal mass and evaporative cooling but considering that they are not a good thermal insulation, they should only be used as an option for the replacement of the original vegetation replaced by the refurbishment

[a] Measures described in Burton (2012).
[b] Measures described in Baker (2009).

Appendix 4
Description of technical measures and their characteristics for windows.

Building refurbishment – dwellings		
Technical measures		Technical characteristics
Windows		
Reduction or increase of framing[a]		Reduction or increase of framing to improve light and view conditions
Installation of a secondary glazed screen (second skin)[b]		It consists of high performance glazing screen and thermally insulated framing inside or outside (weathering layer). It affects the appearance either from inside or outside or in both sides
Replacement of the glazing and the framing system[b]		Existing elements replaced by high performance glazing and thermally insulated framing
Reduction or increase of existing aperture/glazed area[a]		Changes of the aperture area to improve daylight conditions, as for example reduction of heat loss and unwanted solar gain, provision of more wall space for furnishings and equipment.[b] Changes of aperture area is applied as a last option. Before other causes for poor daylight performance should be eliminated first, e.g. low transmission of glass, obstruction due to framing or poorly designed fixed shading devices, low reflectance of interior surfaces or internal obstructions
Changing the distribution of glazing by making new apertures to improve daylight distribution[b]		
Implementation of shading[b]	Implementation of external shading	It can be fixed, adjustable or retractable, e.g. overhangs, louvres, vertical fins, blinds and perforated screens (superior thermal performance)
	Implementation of internal shading	It consists mostly of louvres (venetian blinds) and roller blinds (translucent or opaque)
	Implementation of integrated shading	It addresses daylight distribution function as well as selective shading

[a] Measures described in Burton (2012).
[b] Measures described in Baker (2009).

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