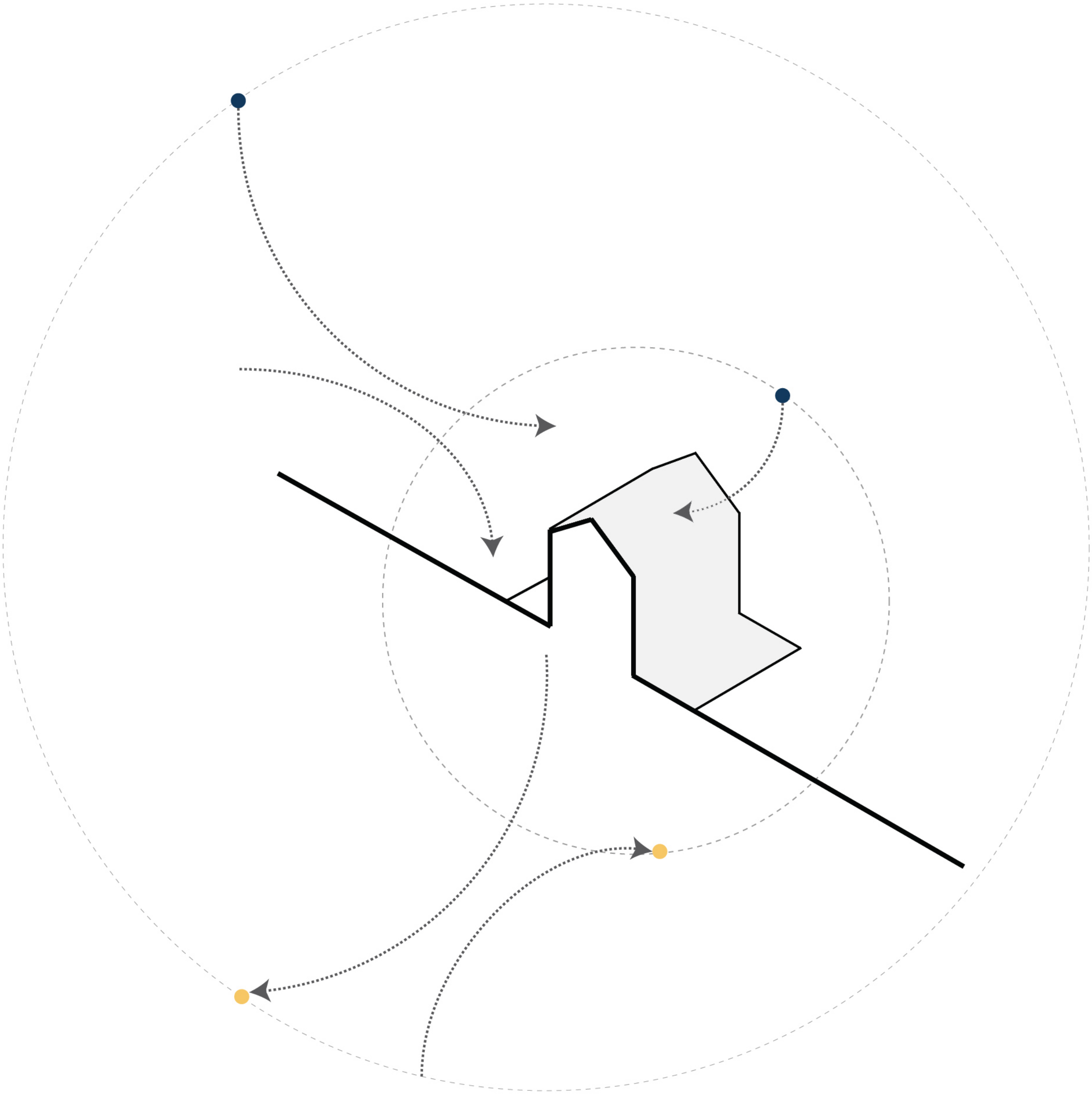

An integrated approach towards energy performance and circularity in buildings

Technical University of Delft | MSc. Building Technology

Graduation thesis

Title : An integrated approach towards energy performance and circularity in buildings.
For the master track Building Technology, part of the Master of Science Architecture, Urbanism & Building Sciences at the Faculty of Architecture and Built Environment, TU Delft.

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A C K N O W L E D G E M E N T S

This research project is a result of work spread across 8 months, during which time quite a few people have helped and supported me, for which I am eternally grateful. Firstly, I would like to thank my graduation mentors, Sabine Jansen and Bob Geldermans for their guidance, wisdom, patience and knowledge.
Their constant encouragement and valuable input has guided and lifted this research into its present state. During this process, they constantly looked out for ways to better and realistically address the posed problem, which led me to learn in-depth about the present state of the built environment. For this I am sincerely thankful.

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A B S T R A C T

Key words: Circularity, energy performance, circular building, integrated assessment, energy assessment, circularity assessment

The built environment consumes 50% of all raw materials, 40% of the total energy and 30% of the total water, in the Netherlands. As climate change looms over and threatens our physical environment, the EU and consequently the Dutch government has proposed multiple stringent regulations to curb our unsustainable resource consumption habits and create a circular economy for the future. The realization of such an economy is currently hindered by the lack of availability of standardized design strategies and assessment methods. In comparison, a high energy performing building can be designed, assessed and operated by following the closely monitored Energy performance building directive initiated by the EU.

The directive lays down stringent goals to be achieved in the built environment every few years. This imbalance leads to the development of a fast paced energy efficient building stock with circular economy ambitions lagging behind.

Addressing this gap, this research focuses on creating and testing an assessment method that measures the energy performance and circularity of a building in an integrated manner, to ensure the equal development of both aspects. In this process, data on new buildings are gathered using which the circular intentions and consequent measures incorporated in these buildings to meet the current building regulations are tracked, resulting in a set of design guidelines for improving the combined energetic and circular performance of a building.

C O N T E N T S

L I S T O F F I G U R E S

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Note: Figures and Tables without a citation are produced by the author

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DEFINITIONS

[1] Energy performance:
(EN 15316-1:2007)
"Calculated or measured amount of energy delivered and exported, actually used or estimated to meet the different needs associated with a standardized use of the building, which may include, inter alia, energy used for heating, cooling, ventilation, domestic hot water, lighting and appliances.
Note: According to EPBD, the energy performance of a building shall be expressed with a numeric indicator of primary energy use, based on primary energy factors per energy carrier, which may be based on national or regional annual weighted average or a specific value for on-site production." (Kurnitski et al., 2015)

[2] Energy demand:
"The building energy provided for end users in the building such as space heating, hot water, space cooling, lighting, fan power and pump power. " (BREEAM UK New Construction, 2014)

[3] Primary energy:
"Energy from renewable and non-renewable sources which has not undergone any conversion or transformation process." (Kurnitski et al., 2015)

[4] Renewable sources of energy:
"Renewable sources can either be available on site e.g. sun, wind or need to be transported to the site e.g. biomass. Therefore, in principle two renewable energy supply options exist: on-site supply and off-site supply, respectively." (Marszal et al., 2011)

[5] Delivered energy:
(EN 15603:2008)
"Energy, expressed per energy carrier, supplied to the technical building systems through the system boundary, to satisfy the uses taken into account (e.g. heating, cooling, ventilation, domestic hot water, lighting, appliances etc) or to produce electricity." (Kurnitski et al., 2015)

[6] Exported energy:
(EN 15603:2008)
"Energy, expressed per energy carrier, delivered by the technical building systems through the system boundary and used outside the energy boundary." (Kurnitski et al., 2015)

[7] Net delivered energy:
(EN 15603:2008)
"Delivered minus exported energy both expressed per energy carrier." (Kurnitski et al., 2015)

[8] Energy efficient:
"A building that uses relatively little energy to provide the power it needs." ("Energy-efficient definition and meaning | Collins English Dictionary," n.d.).

[9] Building related energy
The energy a building requires for heating, cooling, hot water and ventilation (Vancso, 2018).

[10] User related energy
The energy demand for user operated appliances (Vancso, 2018).

[11] Indicator
"Way of assessing the level to which something has been implemented or adhered to." (Circle Economy, DGBC, Metabolic, & SGS Search, 2018).

[12] Circular economy
"An economy where the value of products, materials and resources is maintained in the economy for as long as possible and the generation of waste is minimised." (Suikkanen, Nissinen, & Ari, 2017)

[13] Circularity
"A regenerative approach to resources, and all derived materials and products, based on high quality cycles and ideally without the addition of virgin resources." (Geldermans & Rosen-Jacobson, 2015)

[14] Reuse
"The second hand trading of product for use as originally designed." (Dwek, 2018).

[15] Recycling
"Any recovery operation by which waste materials are reprocessed into product, materials or substances, whether for the original or other purposes, including reprocessing of organic waste but excluding energy recovery." (Suikkanen, Nissinen, & Ari, 2017)

[16] Circular Building
A building designed in such a way that :
(a) The source of material and energetic input is renewable (in technical and biological cycles) with a priority on locally available materials,
(b) Sourcing and end of life of the resource are considered in the design phase,
(c) High grade and indefinite reuse of resources in their most complex forms are accounted for within the design (appropriate to their natural cycles, and within a relevant human time scale),
(d) Reuse of waste in material and energetic form is maximized within the system boundary, and lastly,
(e) Any waste leaving the system boundary is usable as an input in other systems.

I N T R O D U C T I O N

01

1.1 BACKGROUND

The Netherlands has aimed at increasing the efficiency of energy use within the country, with an expected stabilization of Co^2 emissions by the year 2020. In line with this, the Energy Performance of Building Directive (2010) specified that by the year 2020, all new buildings must be 'zero-energy' and must be achieved through cost-effective and passive measures. Additionally, any remaining demand the building may have must generated by sustainable measures (renewable resources) *(Zeiler, Gvozdenović, de Bont, & Maassen, 2016)*. Therefore, it is evident that there is an urgency in sustainability policies dealing with the energy performance of buildings.

Another challenge facing The Netherlands (and many other countries) is the imminent damage to the social and physical living environments due to the mismanagement of natural resources. The Netherlands is highly dependent on third countries and imports 68% of used raw materials from abroad. To manage this challenge under the looming threat of climate change, the Dutch government has introduced a government wide programme for a circular economy, aiming to achieve a 50% reduction in the use of primary raw materials by the year 2030 *("A circular economy in the Netherlands by 2050," n.d.)*.

The aim to achieve a circular economy has many more obstacles as compared to the energy performance of a building. Due to the industrial development and evolution, one fundamental characteristic has remained in the last century: a linear model of resource consumption *(Ellen MacArthur Foundation, 2013a)*. This model follows a take-make-dispose pattern that is unsustainable due to its heavy dependence on limited global commodity stock, and to convert this model into one that fits within the circular economy within the set time period will be challenging. However, if this can be achieved, there are several other spin-off benefits and "opportunities for the Dutch economy, including a stronger technology and knowledge position" *(Verberne, 2016)*.

Additionally, "TNO (2013) estimates that the effects of an expanding circular economy for the entire Netherlands is a total annual saving of 7.3 billion Euros" *(Verberne, 2016)*.

Regenerative Design, Performance Economy, Cradle-to-Cradle, Industrial Ecology, Biomimicry are some of the frameworks (developed since the 1950's) to demonstrate this mismatch between the consumption pattern vs. limited availability of resource *(Pauli, 2011)*. "Some of these frameworks still exist because the urgency is still high."*(Verberne, 2016)*. However, these principles do not yet have a standard implementation strategy that can be universally followed.

From this it can be understood that the policies to achieve a holistically sustainable building stock for the future are in place. However, despite these policies, there is yet no entrenched way of measuring circularity. And thus, in the Netherlands, energy efficiency and high energy performance of buildings are prioritized. "This can unintentionally result in building design with materials that do not lend themselves for dismantling, refurbishment, reuse and high quality up-cycling and thus ultimately for circularity"*(Vancso, 2018)*.

This has created a setback in the complete adoption of the circular economy principles and therefore more dependence on energy efficiency principles to achieve a sustainable design.
Additionally, although the principles of a circular economy are simple to understand and follow, their translation

into practical applications have not been completed sorted out yet. For example, from a circular economy perspective, the extensive use of recycled materials is desired, however, in practice this may lead to many complications and undesirable outcomes *(Gemeente Amsterdam, 2017)*. And in other cases, the interpretation of a circular economy principle in practice does more harm than good. For instance, "In a world with infinite and free energy, it is very easy to design a system that will fully recover materials by means of extremely costly and energy-intensive recycling processes (as seen currently with the recovery of metals from electronic waste)." *(Gemeente Amsterdam, 2017)* But this is not a circular practice.
An integral focus on both the energy performance and circularity of a building is thus necessary to determine and therefore construct a method to bridge this existing gap in order to progress towards a sustainable building stock.

1.2 RESEARCH FRAMEWORK

1.2.1 SCOPE

The scope of this research is restricted to the (1) integrated improvement of energy efficiency and circularity of (2) new buildings.
(1) The literature review is used to understand the concepts of energy efficiency and circularity, as well as existing assessment methods for both. Based on this knowledge integrated improvement suggestions will be proposed. The scale of the design task is determined after the assessment of collected data from the case study, and therefore it is not defined from the start of the project.

(2)A majority of the buildings that will be present for the following few decades have already been built *(B. Geldermans & Rosen-Jacobson, 2015)*. This fact is acknowledged and understood, however, existing building stock imposes many obstacles for assessment from a circular point of view as the decision to build in a circular manner needs to be taken from the early design stage, which if not done could lead to building stock that does not lend itself for many circular principles, such as disassembly and/or adaptability.
This research chooses to focus on new buildings, to define how circular interventions taken during the design process of buildings can improve resource preservation. While this will be directly applicable to the future building stock, it can also be applied to certain layers (structure/facade etc.) in renovation projects.

1.2.2 PROBLEM STATEMENT

Main Problem statement:

The concepts and policies to design, on one hand an energy efficient building and on the other hand, a circular building are in place. However, there exists a lack of standard implementation strategies to integrate them, to create a holistically sustainable building.

Sub-problems:

i. New buildings are being designed to be both energy efficient and circular, but the extent to which this has been achieved is not known.
ii. There is currently no integrated assessment method to assess both energy performance and the degree of circularity adopted in a building.

1.2.3 OBJECTIVE (S)

The objective of this research project is as follows:

1. Present literature findings on concepts, design strategies and assessment methods/criteria that facilitate energy efficiency and circularity in buildings. This theory provides background knowledge on how the topics can be integrated.
2. Then, through data collection of new buildings, practical data on the extent to which these principles have been integrated is presented. This provides feedback on multiple topics: (a) understanding on the interpretation of circularity by self-builders, (b) identification of design factors that lack an integrated approach that combines energy and circularity, (c) Data on the possible synergies and trade-off's between the two topics.

The sub-objectives are:

3. Propose an assessment method that combines the principles of energy performance and circularity so that the assessment can be conducted in an integrated manner.
4. Propose guidelines to improve the overall degree of circularity in a building.
5. As the case study used in this research is a novel and innovative development, there will be multiple interesting and innovative design and technical measures applied to make the buildings sustainable. A sub-objective is to create an inventory of these measures applied along with the user satisfaction of these measures so that future residents of the development can use this open source information to build their homes in a better manner.

1.2.4 RESEARCH QUESTIONS

Main question:

To what extent are high energy performance and circular ambitions combined and achieved in new buildings, and how can this performance be further improved?

Sub-questions:
1. What are the current design strategies, assessment methods & criteria used to achieve a high energy performance building?

2. What are the current design strategies, assessment methods & criteria used to achieve a building with circular economy ambitions?

3. Which approaches, or measures are used in reference projects having both high energy performance and circular ambitions?

4. How can the energy performance and circularity of buildings be assessed in an integrated way?

a. What is the data needed for the assessment of energy performance and circularity of new buildings?

5. To what extent have high energy performance and circular principles been combined in the case study buildings? Are there synergies and/or incompatibilities?

a. What are the design guidelines that can be developed to improve the integration of circular and energy efficient design in the case study buildings?

6. How can the selected case be improved to better combine high energy performance and circular principles and achieve greater synergy between them?

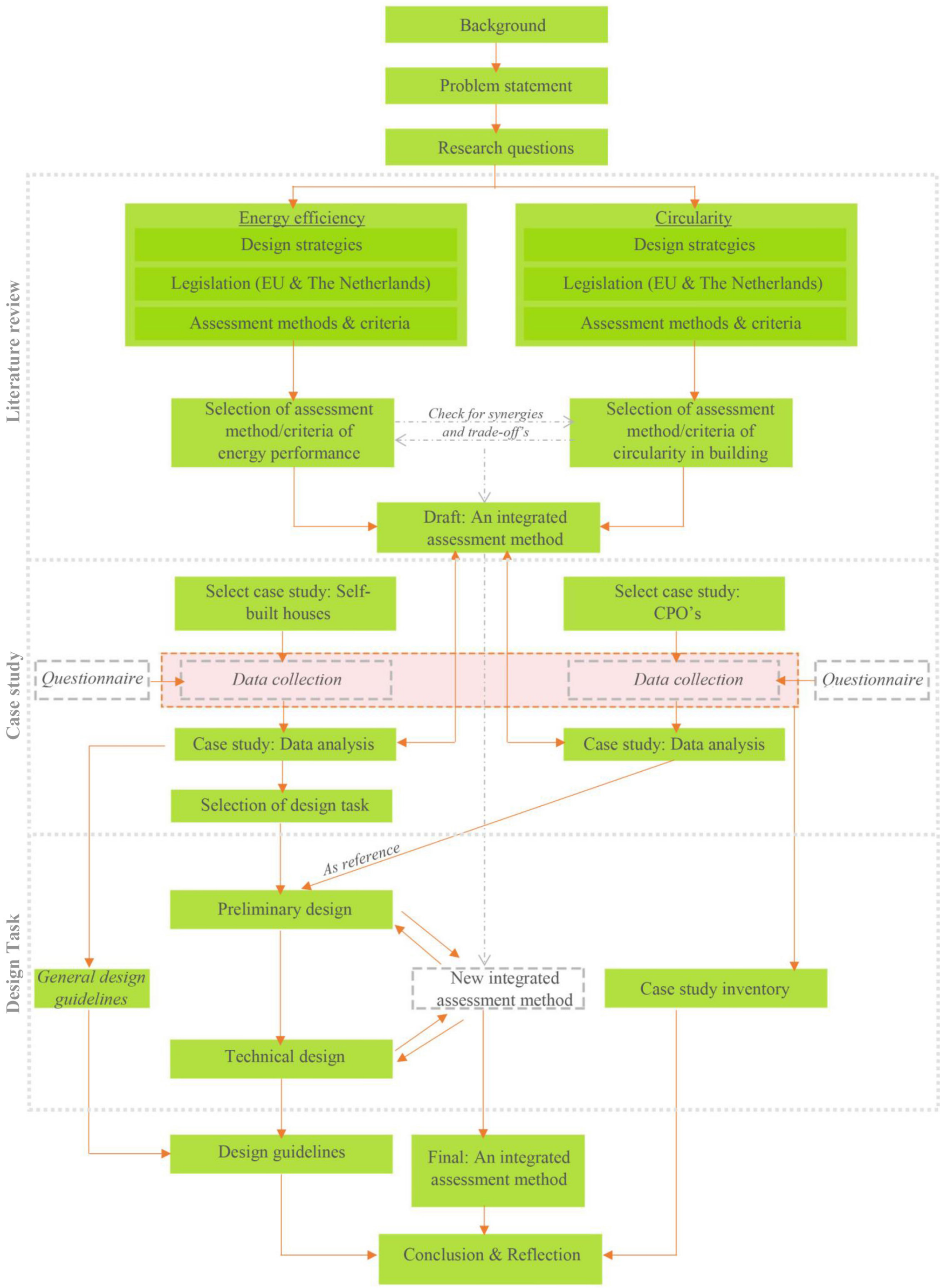
7.How can the integrated assessment method be improved?

1.2.5 FINAL PRODUCTS

The aim of this research is to create a framework and method for integrated assessment of new buildings, and test this on a case study development. Therefore, also gathering practical data on the extent to which the newly built building stock is both energy efficient and circular.

Research sub-question	Outcome
1.What are the current design strategies, assessment methods & criteria used to achieve a high energy performance building?	A literature review about energy performance of a building sub-categorized into the design strategies, legislation (in EU and the Netherlands), assessment methods and criteria.
2. What are the current design strategies, assessment methods & criteria used to achieve a building with circular economy ambitions?	A literature review of circular buildings sub-categorized into the design strategies, legislation (in EU and the Netherlands), assessment methods and criteria.
3. Which approaches, or measures are used in reference projects having both high energy performance and circular ambitions?	A literature review of planned and/or realized projects with high ambitions for circularity and energy performance.
4. How can the energy performance and circularity of buildings be assessed in an integrated way? a. What is the data needed for the assessment of energy performance and circularity of new buildings?	An integrated assessment method that combines both energy and circular aspects, based on literature review on individual assessment tools of both. The method is improved and further developed by an iterative approach. a. Questionnaire with questions related to the energy performance and circularity ambitions of new buildings.
5. To what extent have high energy performance and circular principles been combined in the case study buildings? Are there synergies and/or incompatibilities? a. What are the design guidelines that can be developed to improve the integration of circular and energy efficient design in the case study buildings?	Analysis and comparison of the collected data using the integrated assessment method, compiled into an inventory. a. General design guidelines that integrate circularity and energy efficiency, based on the analysis of the case study buildings.
6. How can the selected case be improved to better combine high energy performance and circular principles and achieve greater synergy between them?	A preliminary and technical design of a design task, based on results of case study analysis, concepts studied in the literature review.
7.How can the integrated assessment method be improved?	Iterative approach of developing, applying and improving the assessment method.

1.2.6 METHODOLOGY



Literature review:

1. Literature review of energy efficiency and circularity (in buildings) in the following sub-categories:
   a. Design strategies: The currently used design strategies that lead to a building with (1) high energy performance (2) a degree of circularity.
   b. Legislation: The policies in place within the EU and the Netherlands.
   c. Assessment methods & criteria: The different methods and criteria currently available/used to assess the energy performance and circularity of buildings.
2. Select assessment methods and/or criteria, study their trade off's and synergies and integrate them into an assessment method or set of criteria.

Case study:

1. Contact residents of self-built houses and stakeholders of Collectief Particulier Opdrachtgeverschap's (CPO's) to be part of this research (for a qualitative set of data).
2. Prepare and distribute questionnaires, based on the draft integrated assessment method.
3. Analyse the collected data using the draft integrated assessment method. Adapt the assessment method if needed and re-analyze the data.
4. Compare the results of the analysis of similar cases.
5. Select the design task based on the analysis of the cases.

Design Task:

1. Develop a preliminary design of the design task based on literature review and results of the case study analysis.
2. Assess and improve the preliminary design using the integrated assessment method.
3. Adapt and improve the integrated assessment method according to the design.
4. Develop a technical design and final integrated assessment method, from the iterative process of improving the preliminary design and assessment method.
5. Convert the data analysis of the case study into general design guidelines.

Final Products:

1. A set of general design guidelines and a final technical design.
2. An integrated assessment method that has undergone multiple iterative processes of improvement.
3. An inventory of the results from case study analysis.

Integrated assessment method:

The objective of the integrated assessment method is to improve the existing circularity and energy performance assessment methods and address the two aspects in an integrated manner. The resultant should be an assessment method that is better applicable to building design.

The methodology prescribed to create an integrated assessment method is:

1. Develop a design strategy from the literature review, that addresses both energy performance and circularity in a building and modify if required.
2. Develop relevant indicators within the assessment methods of energy and circularity that have either synergies or trade-off's with each other.

3. Analyse the trade-offs and synergies between indicators and either directly integrate them or integrate after applying additional criteria.
4. Analyse the first draft of the assessment method using the data collected on the case study buildings. Check the assessment method for discrepancies during the analysis, and adapted accordingly, and also adapted to better suit the case study if required.
5. Analyse the preliminary design with the improved assessment method and reversely assess the assessment method with the preliminary design. Adapt and improve if required.
6. Lastly, analyse the technical design with the improved assessment method and reversely study the assessment method with the technical design. Adapt and improve if required.

1.2.7 RELEVANCE

Social Relevance

The way in which virgin materials and other resources are currently used needs to be improved to avoid depletion of natural resources crucial to our sustenance on this planet. Statistically, the Netherlands is highly dependent on third countries for raw materials, and also, the construction sector accounts for 40% of the total energy consumption *("A circular economy in the Netherlands by 2050," n.d.)*.
The current policies for achieving zero-energy buildings by 2020 is pushing the energy sector forward. However, it is yet to be determined if the circularity of these buildings is being compromised at this advanced rate.

Therefore, the social relevance of this research can be defined as the following:
i. The results from the case study assessments of new buildings can be used to create design strategies for better integration and efficient use of resources.
ii. Better implementation of circular strategies in a building ensures greater longevity and adaptability for future use.
iii. Better application of circular strategies brings with it significant financial gains (e.g., lowered cost of materials, easy replacement of elements without demolition etc.)

Scientific Relevance

Data suggests that the existing building stock in the Netherlands do not have the capacity to transform and adapt to changing market requirements. Between 2010-2040, it is predicted that 600,000 dwellings will be replaced with new dwellings and an estimated 1 million new homes will be constructed *(Investeren in Nederland, 2015)*. By improving the stand of future building stock within the circular economy, further resource depletion can be avoided, while efficiently meeting building material demand.

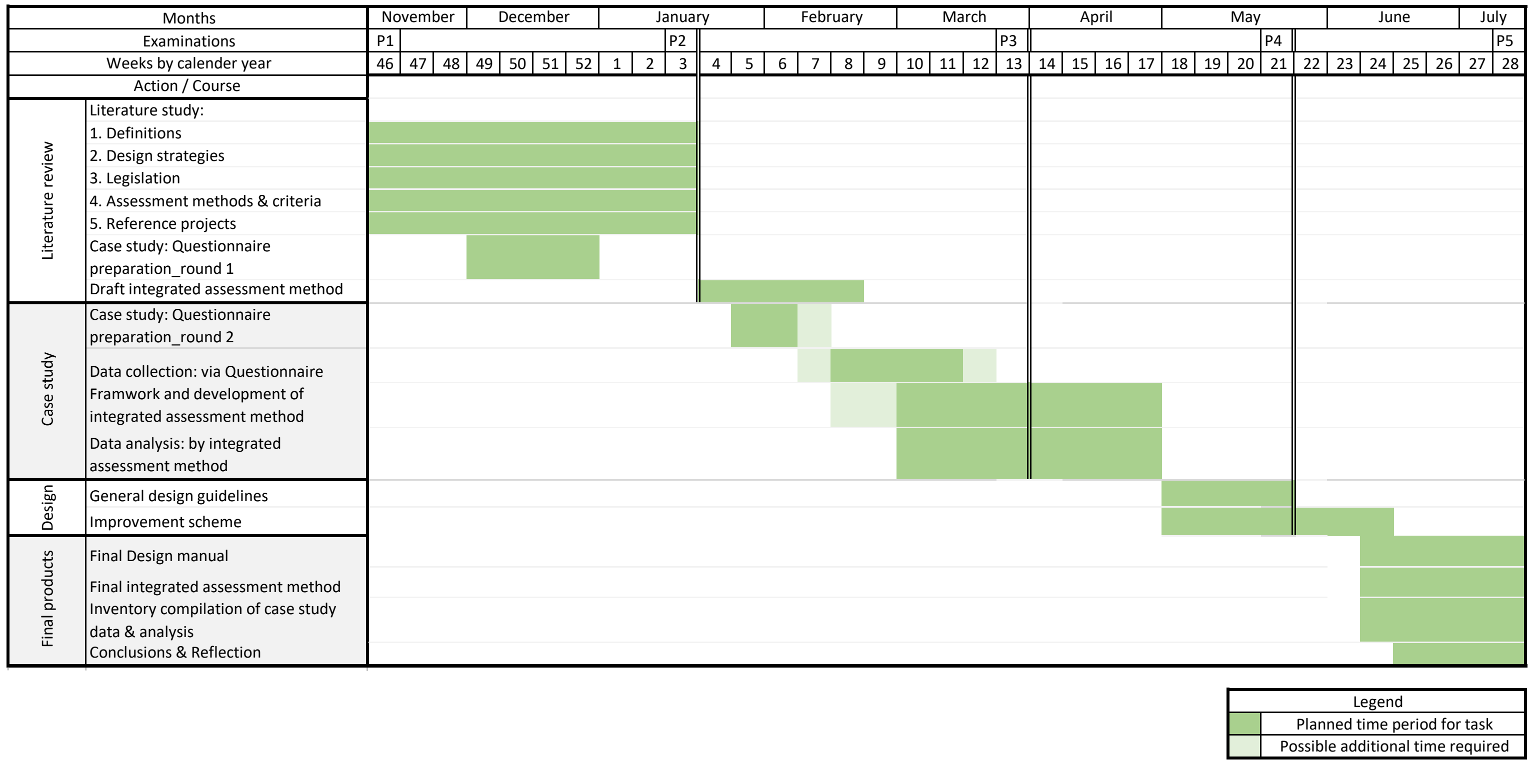
Furthermore, the Dutch government has introduced a programme prescribing that by 2050, "buildings and other structures must be built, (re)used, maintained and demolished sustainably; must be energy neutral and made of sustainable materials" *("Transition to a circular economy | Circular economy | Government.nl," n.d.)*. The first step to achieving this ambition is another programme that aims at reducing the use of primary raw materials to 50% by the year 2030.

These goals are being researched in multiples ways: possible business models, product services for resource efficiency, proposals on waste reduction and more.
This research aims to contribute towards this goal and focuses on the role of building technology choice, that impact not only the pre-design stage but also the operation period and end of life of a building.

Topic relevance in Master track & programme

The theme of this topic is Energy Transition, which is a field of research and practice directly concerned with Building Technology. The aim of the Building technology track is to design and realize sustainable building components efficiently. This graduation research aims for the same. Energy efficiency and circularity are two principles that the built environment is heavily dependent on to create a sustainable building stock. As a scientific research with focus on technical design, this research topic falls under MSc AUBS programme.

1.2.8 TIME PLANNING



LITERATURE REVIEW

02

This section answers the following sub-research questions:

1. What are the current design strategies, assessment methods & criteria used to achieve a high energy performance building?
2. What are the current design strategies, assessment methods & criteria used to achieve a building with circular economy ambitions?

Aim of the research: To explore and understand the current standing of energy performance and building circularity in the built environment: the standards in place that would possibly facilitate the movement of the built environment to a more sustainable future, or hinder it; and methods that can be used to measure the degree to which a building can be called 'circular' or, 'energy efficient' or both.

2.1 ENERGY EFFICIENCY IN THE BUILT ENVIRONMENT

2.1.1 INTRODUCTION

"Buildings and building operations account worldwide for about 40% of the global anthropogenic carbon emissions, including construction, operation, renovation, supply and maintenance" *(Yudelson & Meyer, 2013)*. At present, most of the energy used for building operations is through the exploitation of fossil resources, which will gradually deplete, and seriously implicate climate change *("Improving energy efficiency in the built environment," n.d.)*. Accounting for this looming threat, the energy performance of buildings has been receiving growing global attention over the past half-decade.

"Most people realize that global climate change can only be addressed by tackling the issue of energy performance of buildings, as we strive to build and rebuild more sustainable cities" *(Yudelson & Meyer, 2013)*

However, energy savings in buildings requires more than just better windows, heavier insulation, demand-control ventilation and other passive measures *(Yudelson & Meyer, 2013)*. Concepts such as Passive house, 3-litre, plus energy, Minergie Effinergie, zero-energy and many more are being adopted around Europe to achieve a highly energy efficient building *(Boermans et al., 2011)*. Of these concepts, zero-energy is a "realistic solution for the mitigation of CO^2 emissions and reduction of energy use in the building sector" *(Marszal et al., 2011)*.

2.1.2 ZERO ENERGY BUILDING

Torcellini et al.: "In concept, a net ZEB is a building with greatly reduced energy needs through efficiency gains such that the balance of the energy needs can be supplied by renewable technologies" *(Torcellini, Pless, & Deru, 2006).* Examples of some of the currently used renewable technologies are Solar (PV) panels, Solar collectors, Wind turbines, Biogas generator etc. "A good ZEB definition should first encourage energy efficiency, and then use renewable energy sources available on site" *(Torcellini, Pless, & Deru, 2006)*.

'Zero' balance can be measured in more than one unit, such as delivery energy, primary energy, CO2 emissions, exergy and so on. In this research, the focus is placed on delivered energy as opposed to primary energy.

According to the international standard EN 15603:2008, energy rating calculations should only include the energy use that "does not depend on the occupant behaviour, actual weather conditions and other actual (environmental and indoor) conditions" *(Marszal et al., 2011)*. Table 1.0 summarizes some of the various types of energy associated with a building. In this thesis, operating and construction phase energies are studied to a certain extent. Retrofit and demolition phase energies are important aspects to be considered in the design phase itself, however these are beyond the scope of this research.

Construction phase	
Embedded energy	Building materials, installations, machines etc.
Construction energy	For operating machines and for transport of materials & goods
Operating phase	
Climate	Heating, cooling and ventilation
Lighting	Lighting of all rooms, halls, corridors etc
Machines, appliances	User related appliances eg: computers, fans etc
Operating and control	Building management systems
Transport	Transport of people and goods to and from the building
Retrofit Phase	
Embedded energy	Building materials, installations, machines etc
Construction energy	For operating machines and for transport of materials & goods
Demolition Phase	
Demolition energy	For operating machines and for transport of materials & goods

Table 1.0 Various energies associated with a building *(Torcellini et al., 2006)*

2.1.3 DESIGN STRATEGIES

The Energy efficiency of a building depends on four main factors:

1. Passive solutions: Relating to the quality of materials and construction solution of the external wall of a building
2. Active solutions: Oriented towards efficiently producing energy to meet the demands of a building
3. Operation & Maintenance: The manner of using a building and its resources
4. Feedback & Monitoring: Systems of automation and control of all technological installations of a building, and systems of technical management in a building

(Yudelson & Meyer, 2013)

Torcellini et al generated the following table (Table 2.0) of hierarchical options for the supply of renewable energy in zero-energy buildings:

Option number	ZEB supply side options	Examples
0	Reduce site energy through low-energy building technologies	Daylighting, high-efficiency HVAC equipment, natural ventilation, evaporative cooling, etc.
On- site supply options		
1	Use renewable energy sources available within the building's footprint	PV, solar hot water, and wind located on the building
2	Use renewable energy sources available at the site	PV, solar hot water, low-impact hydro, and wind located on-site, but not on the building

Off- site supply options		
3	Use renewable energy sources available off site to generate energy on site	Biomass, wood pellets, ethanol, or biodiesel that can be imported from off site or, waste streams from on-site processes that can be used on-site to generate electricity and heat
4	Purchase off-site renewable energy sources	Utility-based wind, PV, emissions credits, or other "green "purchasing options.

Table 2.0 Options for supply of renewable energy *(Torcellini et al., 2006)*

1. Passive solutions:

The first step in achieving an energy efficient building is minimizing the energy required for building operation, through passive measures incorporated within the design and construction of the building envelope. Examples of these measures are as follows:

i. Passive solar design:

Solar radiation admitted into a building must be managed as if it is left unmanaged it can cause the space to warm up rapidly during the day leading to an increase in the dependency on cooling techniques.

There are five elements within a building that can collect and manage solar radiation:

a) Aperture: Windows and other openings through which sunlight enters.
b) Absorber: The surface of the storage element.
c) Thermal mass: Materials of higher mass in the building to store heat.
d) Distribution network: Channels to circulate the collected heat.
e) Control: Shading elements for the aperture especially during summer months.

ii. Double envelope:

Thermal buffer spaces created within box-in-box constructions that produce very efficient buildings. However, this layering is possibly a wasteful use of materials.

iii. Solar Orientation:

The optimization of building orientation allows for the thermal mass within to be use efficiently.

iv. Surface to Volume ratio:

Reducing the exposed surface in comparison to the volume of space.

v. Windows and glazing:

There is a point of diminishing returns when it comes to large openings/windows. Strategically placed windows are advantageous to the thermal qualities of the interior elements.

vi. Insulation:

A well insulted building allows for reduced heat losses and better thermal comfort for its occupants. However, excessive insulation is a wasteful use of materials and beyond a point, reaps no additional benefits. Also, the application of appropriate insulation material is imperative. For example, fibreglass insulation is not good at filling gaps between pipes and wiring, so should not be used for this purpose.

(Yudelson & Meyer, 2013)

2. Active solutions:

Active solutions refer to methods of efficient energy generation required to meet the heating and cooling demands in a building arising despite the passive techniques applied to reduce the overall energy demand. This extends to using renewables, energy saving gadgets and efficient control systems. Some of the active solutions are listed in Table 3.0:

Technology	Application
Radiant heating/cooling	Underfloor heating
Heat exchanging magneto caloric	Shower heat exchanger
Solar collectors	Hot water production
Solar cell systems	Windows, LED lights
Wind turbines	Small and medium sized to produce electricity for grid
Biomass generator	Biogas for cooking
Hydrogen fuel cells	Produce electricity (heat and water) at moments of shortage
Heat exchanger	Ventilation with heat recovery
Ground source heat pump	Transfer heat to and from the ground
LED	Efficiency and energy savings in lighting

Table 3.0 Active solutions to achieve an energy efficient building *(Adapted from Torcellini et al., 2006)*

3. Operation and Maintenance

The installation of sustainable energy systems alone cannot guarantee a sustainable building. The operation and maintenance of a building forms a large part of the annual energy consumption and depends on the "green" behaviours of the occupants. "People are not easily convinced of the need to take measures to improve the energy performance of their houses, even when financial benefits outweigh the costs" *(Middelkoop, Vringer, & Visser, 2017)*. In the Netherlands, "both owners and tenants (50-70%) support government policy on energy performance improvements to existing homes" *(Middelkoop, Vringer, & Visser, 2017)*.

4. Feedback and Monitoring

Regular feedback and monitoring of the energy meters placed in individual homes, by consumers allows them to reflect upon the energy usage (supply and use) and modify behaviours or systems to achieve greater long term efficiency.

2.1.4 LEGISLATION

In the Netherlands, residential buildings are responsible for about 9% of the CO^2 emissions of the building sector *(Schoots & Hammingh, 2016)*. In order to reduce the European Union's dependence on non-renewable sources of energy and consequently the release of greenhouse gases, measures that firstly, achieve reduced energy consumption and secondly, rely on renewable resources must be applied. Significant propositions of the European Union's regulatory framework to achieve this are the energy performance of buildings directive 2002/91/EC (EPBD), and its recast. "The recast of EPBD has several strengthened requirements such as the obligation that all the new buildings should be nearly zero-energy by the end of 2020. The transportation of these Directives into national legislation influences the achievement of energy saving targets" *(Annunziata, Frey, & Rizzi, 2013)*.

"In October 2014, the European Council agreed on the 2030 climate and energy policy framework for the EU setting an ambitious economy-wide domestic target of at least 40% greenhouse gas emission reduction for 2030" *("European Commission - PRESS RELEASES - Press release - Clean Energy for All Europeans – unlocking Europe's growth potential," n.d.).*

A few of the many measures adopted by the EU are:
1. An annual reduction of 15% in national energy sales.
2. Energy efficient renovations to be made to a minimum 3% of the household building stock.
3. The preparation of National Energy Efficiency Action Plans every three years by EU countries.
4. Providing consumers with free real time data on their energy use and consumption.
5. A publication of guidelines related to energy efficient measures.
("Energy Efficiency - European Commission," n.d.).

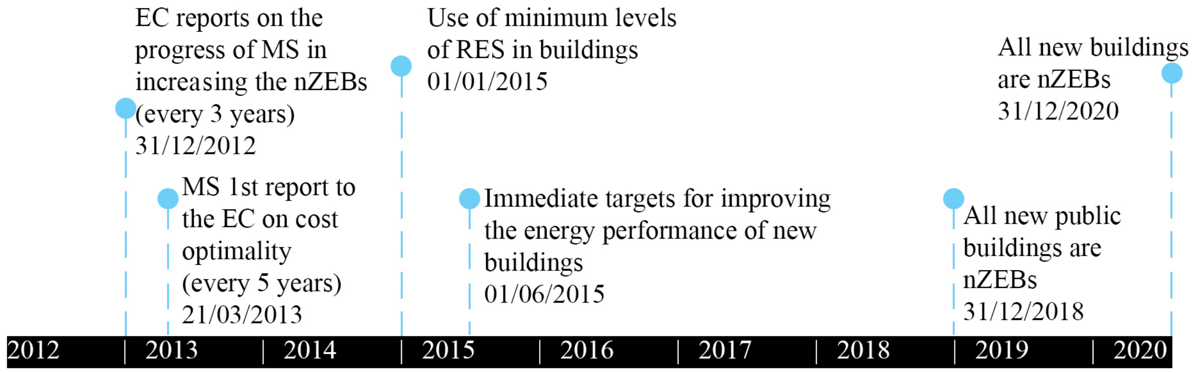


Figure 1.0 Key years for nearly Zero-Energy buildings *(Directive 2010/31/EC) (Atanasiu et al., 2014)*

Country	Translation of investments in energy savings into economic value		Commitment towards "nearly zero-energy" targets		
	Incentives for sale of energy efficient buildings	Incentives for rent of energy efficient buildings	Penalties for energy performance requirement non-compliance	Minimum threshold for the mandatory communication about the effects	Incentives for nearly zero-energy buildings
Netherlands	R	X	X	R	X

X = national regulations, R = regional/local regulations
Table 4.0 Summary of regulatory instruments adopted by the Netherlands *(Hermelink et al., 2013)*

Figure 1.0 and Table 4.0 sum up the regulations in the EPBD directive(2010/31/EC) and the current legislations in the Netherlands regarding the energy performance of a building.

Energy Prestatie Coefficient (EPC)
The Energy Prestatie Coefficient (denoted as a number) of a building informs designers and users of the performance of the building, while also informing them of areas of possible improvements. Currently, the regulation states a maximum EPC value of 0,4 in residential buildings. As of the 1st of July 2020, the Netherlands will transition to the use of BENG instead of EPC as the energy indicator for almost energy neutral buildings. The three indicators of BENG are:
1. The maximum energy requirement in kWh per m 2 usage area per year
2. The maximum primary fossil energy consumption, also in kWh per m 2 use area per year
3. The minimum share of renewable energy in percentages
("Energy Performance - BENG RVO.nl," n.d.)

Bouwbesluit - Dutch Building Decree
Bouwbesluit refers to the Dutch Building Decree, which is a set of regulations all new buildings and renovations must comply by. "A building may not present any danger to residents, users and the environment. That is why the government has laid down regulations for safety, health, usability, energy efficiency and the environment in the 2012 Building Decree" *("Building Decree 2012 | Building regulations Rijksoverheid.nl," n.d.).*

The minimum Bouwbesluit standard for thermal resistivity of building layers are:
Floor: Rc-3,5 m²K/W, Roof: Rc-6,0 m²K/W, Facade: Rc-4,5 m²K/W

In addition to regulations on the energy efficiency of buildings, the Bouwbesluit also lays down minimum standards for the environment impact of the building. This extends to material use in construction including extraction, production, transportation, demolition and reuse/recycling *("Building Decree 2012 | Building regulations Rijksoverheid.nl," n.d.).*

2.1.5 ASSESSMENT TOOLS

The following tools can be used to assess the energy efficiency of a building:

Energie-index
Energy index is the new energy label within the Netherlands, to be used for measuring the energy performance of homes, especially by landlords. The use of this label is mandatory according to the Energy Performance Building Directive.

Uniec
Uniec is an online platform that can be used to make EPC calculations, energy labels and energy index calculations for residential and non-residential buildings.

Enorm
Enorm is a software package available for making the same calculations as Uniec, namely, EPC, energy index and energy labels.

Honeybee & Design builder, Trnsys
Trnsys is a dynamic simulation tool that can be used for the assessment of the thermal and electrical energy performance of a system. Design builder and Honeybee are other dynamic simulation tools that can be used to predict a buildings energy use within a certain time period.

Figure 2.0 (Top to bottom) Energie-Index, Uniec 2.2, Enorm, Honeybee, Design builder, Trynsys

2.2 CIRCULARITY IN THE BUILT ENVIRONMENT

2.2.1 INTRODUCTION

The construction sector is estimated to be consuming "50% of all raw materials, accounting for 40% of the total energy consumption and 30% of total water" in the Netherlands *("Transition to a circular economy | Circular economy | Government.nl," n.d.)*. Besides this, construction and demolition waste also accounts for 24 million tonnes of the total waste production, almost equivalent to the total industrial and consumer waste combined (Figure 3.0).

As climate change, resource depletion, biodiversity extinction and more are looming over the future, the Dutch government is pushing for a circular economy by the year 2050. This does not merely reflect on the quantity of available natural resources for the construction industry. The total amount of renewable energy available on the planet can be considered finite if solar power is taken into account, however, the extraction of these resources into useful form requires the use of scarce materials, thus limiting us. And prompting an urgent requirement for a circular economy.

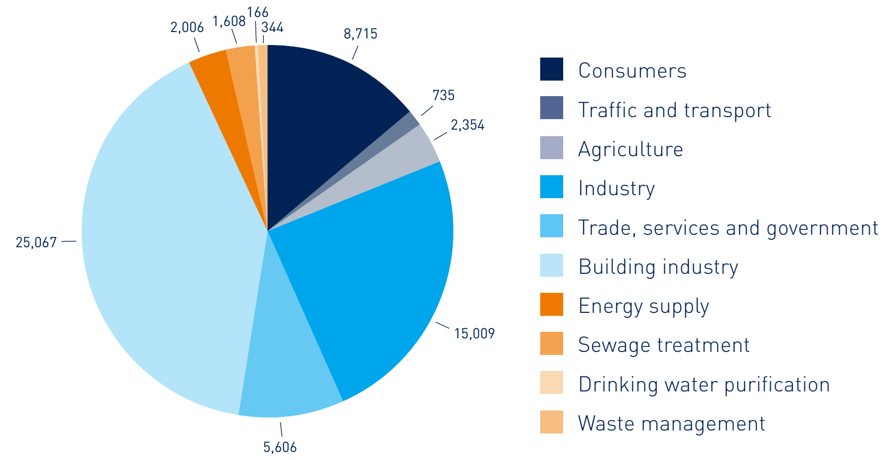


Figure 3.0 Total waste arising in the Netherlands (in 2012) 6. *("Collection & Recycling - Solar Waste / European WEEE Directive," n.d.)*

2.2.2 THE CIRCULAR ECONOMY

It is first crucial to understand the current model of resource consumption, to know where the change needs to be made.

Conventionally, a building may have a functional life span of approximately 50-75 years, however, buildings now are being demolished much sooner *("Themes – Green Design Conference," n.d.)*. A majority of this construction and demolition waste is ultimately disposed off in landfills. This model of resource consumption refers to a linear economy.

A linear economy by definition, uses raw materials to produce a product, that is thrown away as waste at the end of its functional life (or when discarded). Another type of resource consumption is within the reuse economy. Principally in this economy, the inputs of a product are reused at the end of life of the product itself. This model reduces waste and ensures that materials are used efficiently.

The third type of model (Figure 4.0) i.e., a circular model fits within the principles of a circular economy and is the model towards which the Dutch government aims to achieve by 2050.

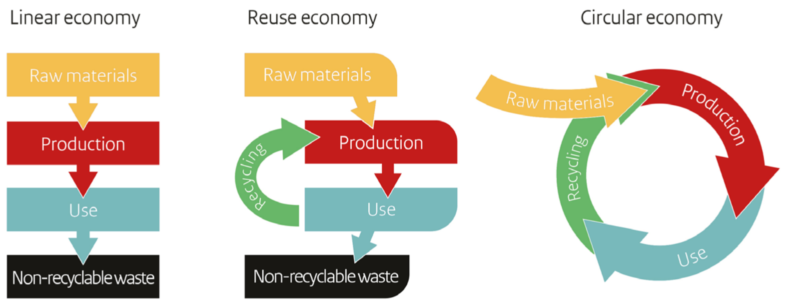


Figure 4.0 Linear to circular economy. 7 ("From a linear to a circular economy | Circular economy | Government.nl," n.d.)

The Circular Economy:

The definition of a circular economy varies between groups of people, companies and countries, and is associated with concepts such as waste as a resource, use of new business models such as leasing, material efficiency and so on. The essence of a circular economy, however, lies in understanding the end state of an element/component/ product /materials *("The Seven Pillars of the Circular Economy —," n.d.).*

According to Metabolic: All materials in a circular economy should be designed or used in such a manner than they can be cycled indefinitely. And this process should be conducted in a time span that is relevant to people. "In a world with infinite and free energy, it's very easy to design and develop systems that will fully recover all materials through extremely costly and energy-intensive recycling processes." *("The Seven Pillars of the Circular Economy —," n.d.)*

The seven pillars of the circular economy by Metabolic:

1. Materials: Materials should be cycled indefinitely or to the maximum possible, in their 'most complex form'. The cycling should take place within a relevant and appropriate (to humans and material cycle) time span. The scarcity of the materials should be considered as a factor determining the period of cycling.
2. Energy: Resources used for the generation should be renewable and the system should be designed in a manner in which waste is minimized.
3. Biodiversity: Human activities should not encroach upon natural habitats, especially rare habitats. "Material and energetic losses are tolerated for the sake of preservation of biodiversity; it is a much higher priority"
4. Human society and culture: "Activities that structurally undermine the well-being or existence of unique human cultures should be avoided at high cost.
5. Health and well-being: The use of toxic materials and substances should be controlled or avoided all together if possible.
6. Value generation: "Forms of value beyond financial include: aesthetic, emotional, ecological etc. And as materials and energy are not available in infinite measures, they should be used in a meaningful manner that creates societal value.

7.Water is extracted at a sustainable rate and resource recovery is maximized: "In a circular economy, the value of water should be maintained, cycling it for indefinite re-use while simultaneously recovering valuable resources from it whenever possible"
("The Seven Pillars of the Circular Economy —," n.d.)

Figure 5.0 is a schematic description of the circular economy as illustrated by the Ellen MacArthur foundation.

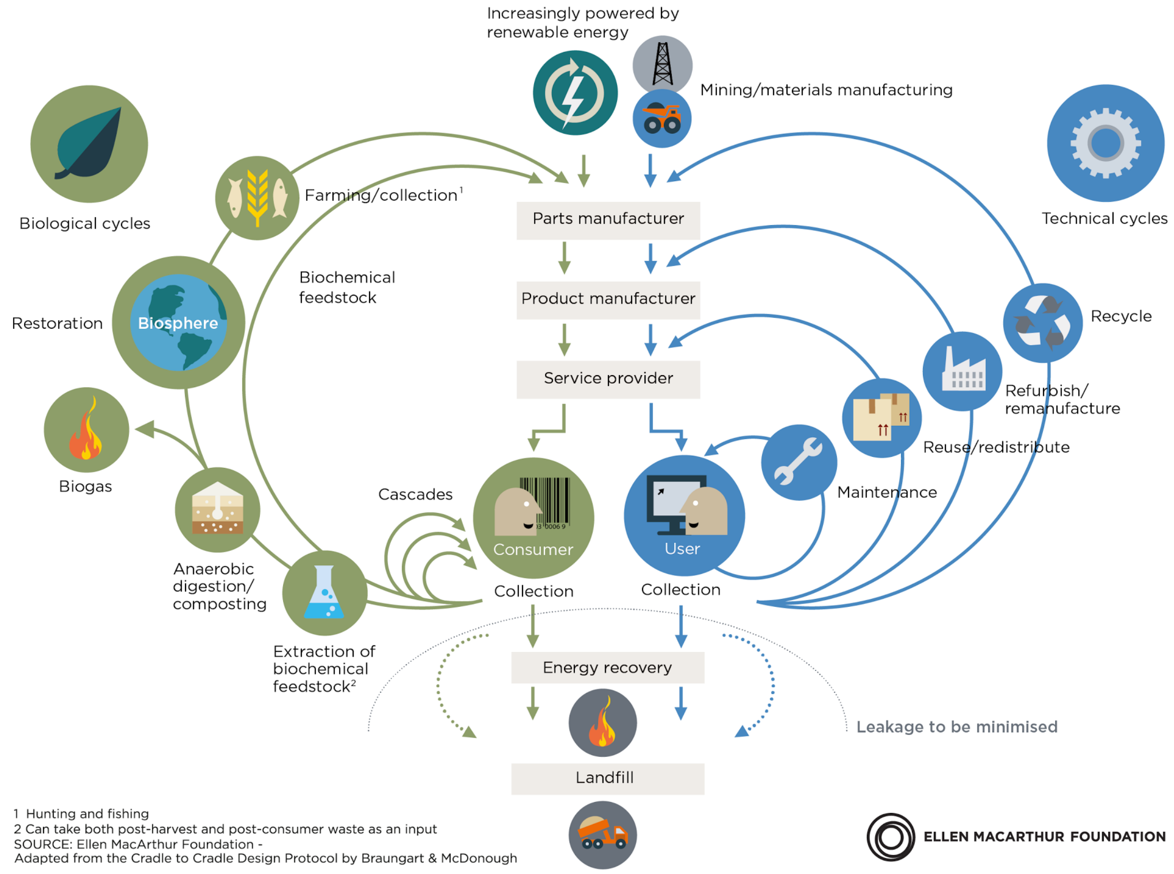


Figure 5.0 Illustration of a circular economy by Ellen MacArthur Foundation *(Allwood, 2014)*

Circular building:

It is imperative to define the meaning of a circular building, for the purpose of this research. Based on the principles of a circular economy, a circular building is understood as: "The design, construction, and demolition of a building are taken into account in such a way that in addition to the high-grade use and re-use of materials, and an adaptive and future-proof design, also durability goals in the field of energy, water, and biodiversity and ecosystems." *(Gemeente Amsterdam, 2017)*

The following stepwise approach is acknowledged as basics for designing a circular building:
1. Evaluate the added value
2. Consider re purposing vacant buildings
3. Integrate 'change' in a new adaptable design
4. Use intelligent dimensioning
5. Prioritize the use of available materials
6. Aim for high quality future reuse
(R. J. Geldermans, 2016)

In this thesis, the **definition of a circular building** has been adapted and defined as:

A building designed in such a way that:
(a) The source of material and energetic input is renewable (in technical and biological cycles) with a priority on locally available materials,
(b) Sourcing and end of life of the resource are considered in the design phase,
(c) High grade and indefinite reuse of resources in their most complex forms are accounted for within the design (appropriate to their natural cycles, and within a relevant human time scale),
(d) Reuse of waste in material and energetic form is maximized within the system boundary, and lastly,
(e) Any waste leaving the system boundary is usable as an input in other systems.

2.2.3 DESIGN STRATEGIES

The principles by Metabolic (mentioned in the previous section) help in understanding circularity as a whole, the standpoints of a circular economy and an indication on how a component/ element/ building can be made circular. This has also been addressed over time by many, and each of these understandings shed light on the concept of circularity, and are therefore explained as follows:

1.0 The six S's:

The six S strategy by Stewart Brand aims to improve the feasibility of building disassembly and adaptability. This need for adaptability arises because the static approach taken towards building design ignores the different degrees of durability present in a building and hence resulting in wastage of resources *(Brand, 1994)*. For example, the structure of a building may have a service life of 75 years, while the cladding may last for 20 years. Similarly, the services could last for 15 years while the interior elements might be replaced at a 3 year frequency. To address this basic distinction developed in building design and execution, Stewart Brand developed the six S framework. The different layers are shown in Figure 6.0 and explained as follows *(Brand, 1994)*:

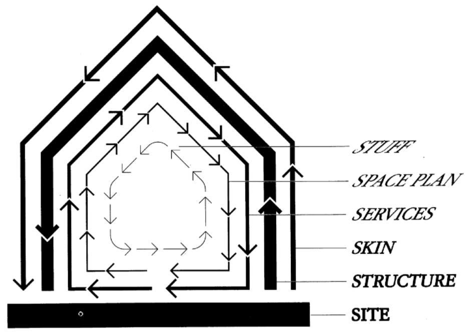


Figure 6.0 Different layers of a building, by Stewart Brand. *(Brand, 2018)*

1.Site: The geographical location consisting of boundaries and context outlasts the functional lifespan of buildings. As said by Architect Frank Duffy: "Site is eternal"
2.Structure: The structural lifespan of a building generally ranges from 30 to 300 years.
3.Skin: The external façade of the building is referred to as the skin and could be replaced at a frequency of every 20 years. This element has a large influence of the heat gains and losses within a building and therefore, the overall energy demand.
4.Services: The electrical, mechanical, plumbing, fire safety lines pertaining to the functioning of a building.
5.Space plan: The interior elements, including but not restricted to walls, floors and ceilings.
6.Stuff: The easily movable and replaceable elements of a building defined by the user. E.g., The furniture
(Brand, 2018)
Table 5.0 shows the adaptability of these different building layers defined by Stewart Brand.

	Stuff	Space	Services	Skin	Structure	Skin
Adjustable (change in task)	✓					
Versatile (change in space)	✓	✓				
Re-fitable (change in performance)	✓	✓	✓	✓		
Convertible (change in use)	✓	✓	✓	✓		
Scalable (change in size)	✓	✓	✓	✓	✓	
Movable (change in location)	✓	✓	✓	✓	✓	✓

Table 5.0 Adaptable aspects of the building layers *(Schmidt III et al. 2010)*

2.0 Cradle to Cradle:

"The Cradle to Cradle philosophy focuses on an ideological transition from 'less bad' to 'more good'" *(Toxopeus, De Koeijer, & Meij, 2015)*. The conventional eco-efficient approaches strive to reduce the ecological footprint to minimize environmental damage, while the Cradle to Cradle approach developed by Michael Braungart and William McDonough focuses on methods to create a positive footprint, achieved through improvements at an industry and economy scale *(Toxopeus et al., 2015).*

Within the Cradle to Cradle framework, the following two metabolic cycles are acknowledged (Figure 7.0):

i. Biological metabolism: Within this cycle, the typical products have materials returning to the environment through water or air emissions, made from renewable sources. The materials in the product can be easily broken down and become part of a new cycle as nutrients.
ii. Technical metabolism: Within this cycle, the typical products do not have any material loss to the environment (during the use phase). The products are made of non-renewable sources, that act as nutrients for new products. These products cannot be easily broken down therefore are kept in cycles of usage by recycling.

Cradle to Cradle is a business model, as said by Michael Braungart, one of the two founders of this concept. While technical and biological cycles are addressed in this concept, the first priority is the relationship between suppliers, and customers.

The Cradle to Cradle philosophy is based on the following three principles:
i.Waste equals food: All materials should be used as nutrients. (In biological metabolism or technical metabolism or product lifecycles)
ii.Use solar income for sustainable energy: Cradle to Cradle products should incorporate only sustainable energy sources.
iii.Improve resilience of a system through diversity: Focus on limited parameters could lead to a static and unstable product in terms of a wider context.
(Toxopeus, De Koeijer, & Meij, 2015)

As explained by Michael Braingart, Cradle to Cradle is not a recycling concept, and therefore is not suitable in the context of waste reduction or other minimization concepts.
The Cradle to Cradle philosophy is a useful tool in designing within the circular economy as it promotes effectiveness ahead of efficient-ness therefore shifting the focus to a more long-term goal that affects the environment positively. This philosophy is not directly applicable in this research as it is more effective as a business tool to certify products but is still referred as it is used as a base for the new stepped strategy by Andy van den Dobbelsteen.

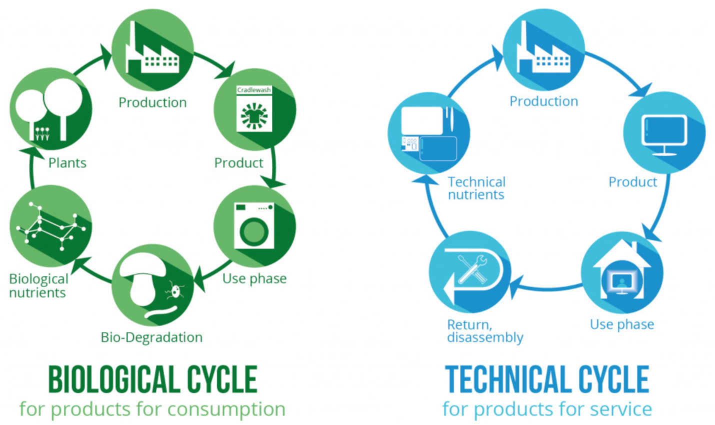


Figure 7.0 Biological vs Technical cycle *("Accreditation by EPEA - Cradle to Cradle CertifiedTM certification and more," n.d.)*

3.0 Life Cycle Analysis:

Life cycle analysis (LCA) is also known as life cycle assessment, and has been used extensively for products, however, the principles also apply to buildings. In this concept, the life of a product, or building, is examined from the origin of its raw materials through the manufacturing process, to the to its consumption during the useful life of the product, ending at its environmental impact at end of life (Figure 8.0).

"At each phase of the life cycle, there are material and energy inputs and corresponding environmental impacts. An LCA attempts to quantify all of these inputs and then come up with values to represent their impact" *(Bergman, 2012).*

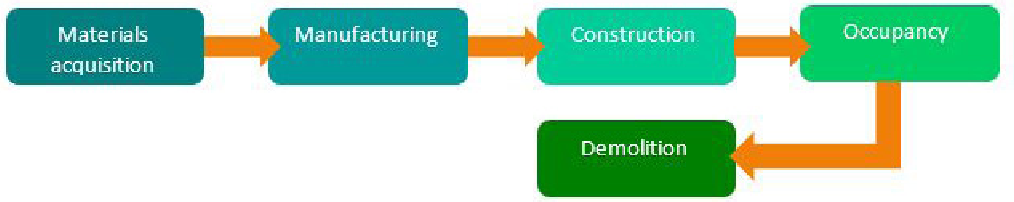


Figure 8.0 Different stages of a product or building that is analysed *(Bergman, 2012)*.

4.0 The Triple Bottom Line:

The triple bottom line is an accounting framework, created for measuring the degree of sustainability an organization has achieved or is pursuing towards. Figure 9.0 shows the principles of the triple bottom line, namely 'people, planet, and profit' or 'ecology, economy, and equity' *(Bergman, 2012)*.

Figure 9.0 Principles of the triple bottom line *("A Simple Explanation of the Triple Bottom Line | University of Wisconsin," n.d.)*

In this research, the aim is to create a sustainable environment, which is within the buildings as well as for the environment. This happens by virtue, if the buildings are designed, constructed, demolished and operated well. Therefore, the different elements of TBL, which is People, Profit and Planet are all important. But the ratio of these to one another, as prescribed in the concept is questionable. In order to sustain life on this planet for a longer term, the planet must be prioritized under all circumstances. As also explained in Metabolic's seven pillars of circular economy: "Material and energetic losses are tolerated for the sake of preservation of biodiversity; it is a much higher priority" *("The Seven Pillars of the Circular Economy —," n.d.)*. Secondly, the welfare and comfort of people should be enhanced and protected. While the remedies and measure should not lead to financial losses, the welfare of people and planet should not be compromised for monetary gains.

5.0 The New stepped strategy:

The Trias Energetica is a sustainable building approach taken for enforcing green and energy efficient measures in a building. As explained in section 2.1.2, the Trias Energetica is based on three strategies:
i. Reducing the demand
ii. Using renewable energy
iii.Supply the remaining demand efficiently
Over the years, this method helped make conscious environmental decisions in the built environment, however it is now considered outdated as it does not serve sufficient sustainable results. It is considered so, because step 2 is often neglected and is followed by a sub-optimal reduction in energy demand *(Van Den Dobbelsteen, n.d.)*.

As a solution, the New stepped strategy was developed by Andy van den Dobbelsteen. The concept is heavily inspired by the Cradle to Cradle approach by William McDonough and Michael Braungart. The new strategy incorporates an additional step in the Trias Energetica method based on the C2C strategy (Figure 10.0), and is elaborated as follows:
In the original strategy, it was determined that step 2: using of renewable energy is insufficiently emphasized. Therefore, an intermediate step: reuse of waste stream is inserted between the steps 1 and 2, thereby avoiding the use of fossil fuels all together. Here, waste streams include all waste flows such as waste heat, wastewater and waste material, at building and city scale *(Van Den Dobbelsteen, n.d.)*.

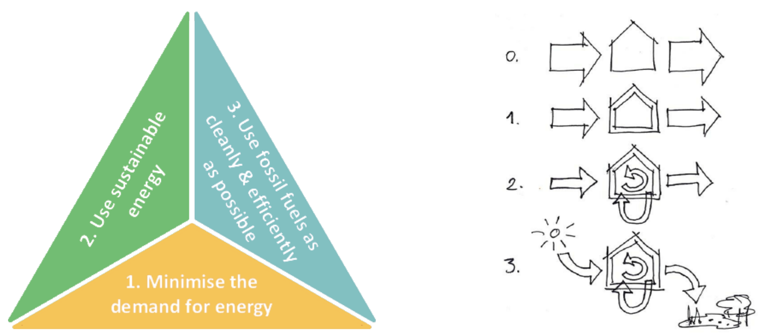


Figure 10.0 Trias Energetica ("Energy in Twente," n.d.) to The new stepped strategy *(Van Den Dobbelsteen, n.d.)*

Namely, the new stepped strategy is:
i. Reduce the demand
ii. Reuse waste streams
iii.Use renewable energy sources (a) and ensure that waste can be used as food (b)
(Van Den Dobbelsteen, n.d.)

This research adapts the new stepped strategy in multiple phases of the study. It is highly compatible with the goals set out for this study, which is to reduce the demand for resources firstly, and then apply eco-efficient methods to achieve a high level of efficiency, thereby creating a sustainable building/ built environment. This strategy incorporates two of the concepts previously explained, namely, Cradle to Cradle and Trias Energetica. The best of both are taken into account, while combating their negative externalities.

6.0 The New stepped strategy adaptation:

The stepped strategy has undergone further modifications, to most importantly fit within the circularity framework. The modified approach distinguishes between the planning and building design, as well as materials and products. The approach takes on step 1 (reduce the demand) from a circular viewpoint, and incorporates intelligent dimensioning as an integral step *(Geldermans & Rosen-Jacobson, 2015)*. The approach is represented in Figure 11.0.

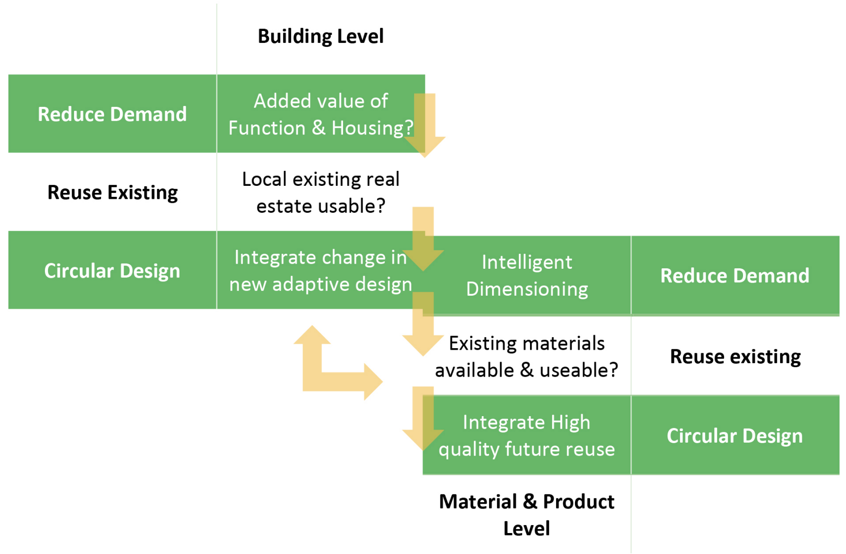


Figure 11.0 Stepwise approach circular building *(Geldermans & Rosen-Jacobson, 2015)*

2.2.4 LEGISLATION

In 2015, the EU introduced an action plan, aiming to transition towards a circular economy. This move facilitates the global boost to foster sustainable economic growth.
The initiative to 'close the loop' encourages sound waste management and aims at creating a market for secondary raw materials. "Together with the Action Plan, the Circular Economy package includes Revised Legislative Proposals on Waste that include targets for recycling, measures for reducing landfill, to promote re-use and stimulate industrial symbiosis, as well as economic incentives for produces to put greener products on the market." *(Circular Economy Action Plan, n.d.)*

In 2018, the European Commission adopted a new set of measures, above and beyond the Circular Economy Action Plan, with the continuing aim to create a sustainable economy. The measures include the following:
I. EU Strategy for Plastics in the Circular Economy
II. A Communication to address interface between chemical, product and waste legislation
III. A monitoring framework on progress towards a circular economy
IV. A report on Critical raw materials and the circular economy
("Circular Economy Strategy - Environment - European Commission," n.d.)

Despite these efforts, "according to a report from European environmental agency (EEA) published in 2016, there is at present no recognized way of measuring how effective the European Union, a Country or even a company is in making the transition to a circular economy, nor are there holistic monitoring tools for supporting such a progress" *(European Environment Agency, 2016)*. The lack of a standardized measurement tool at a micro level, including businesses and products, is hindering the transition to a circular economy.

Nevertheless, it is important to acknowledge the steps the Dutch government is taking towards building up a circular economy. As mentioned in Section 2.1.4, the Dutch building decree now specifies an assessment of the environment performance of the building. Tools such as the Nationale Milieu database is set up to assist in the calculation of the performance, and also acts as a data source for a large number of fixed processes/products and materials. *("Home - Nationale Milieu Database," n.d.)*

2.2.5 ASSESSMENT METHODS

As understood from the previous section, there is currently no standardized tool or strategy adopted to measure the degree of circularity of a product/ building /organization or country. Circular economy models and implementations are usually performed at three systemic level:
i. Macro level: The city, province, region, nation
ii. Meso level: Eco-industrial parks
iii.Micro level: A single building or consumer
(Saidani, Yannou, Leroy, & Cluzel, 2017)

This research focuses on circularity at the micro level and therefore a literature study of existing assessment methods at this scale has been carried out. The assessment methods are based on two types of indicators: quantitative and qualitative. Quantitative indicators are directly related to the product/building performance while qualitative indicators describe a process – a commitment, contract type, referring to a course of action. These tools are developed by various foundations and sustainable consultants, contributing towards the analysis of a material/ product or building in the built environment.

Circularity assessment tools are said to be used as key performance indicators, for product labels, or to initiate legislative changes *(Linder et al., 2017)*.

1.0 Material Circularity Indicator

The Ellen MacArthur Foundation is a registered charity in the UK, that has developed a metric to assess circularity at product and company levels. It is intended for internal reporting or investment decisions *(Saidani, Yannou, Leroy, & Cluzel, 2017)*. The Material Circularity Indicator is freely available as an excel sheet and consists of two factors: a linear flow index and a utility factor.

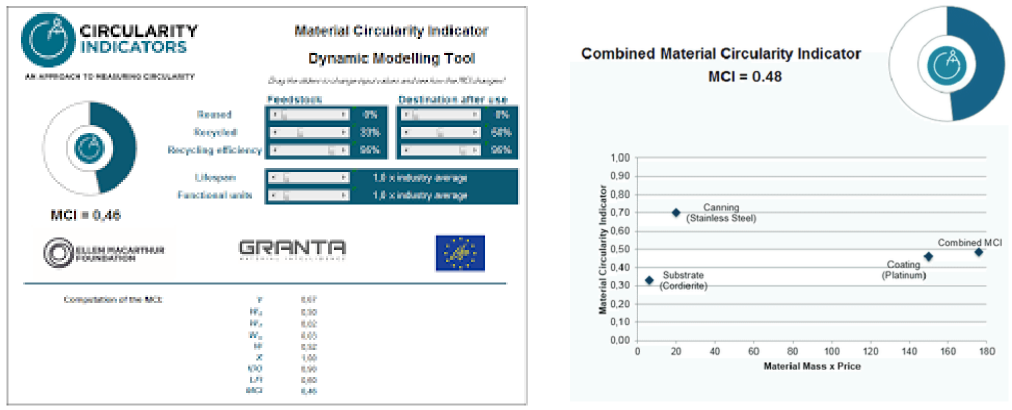


Figure 12.0 Interface of Material Circularity Indicator excel sheet *(Saidani et al., 2017)*

To evaluate multi-materials of products, an additional spreadsheet is provided and a reference for individual products *(Saidani et al., 2017)*.
The inputs required to calculate the index are:
i. Percentage of product made from reused materials
ii. Percentage of product made from recycled materials
iii.Efficiency of recycling process during production
iv.Percentage of product that will be collected for reuse
v. Percentage of product that will be collected for recycling
vi.Efficiency of recycling process after use
vii. Lifespan and intensity of use of the product compare to industry average of a similar type of product

Drawbacks of the indicator:

The development of assessment tools is an ongoing research/process and are not devoid of errors. MCI has the following drawbacks that can be improved further:

i. MCI focuses on mass flow and integrates various materials into a single number. "This creates difficulties in incorporating different types of material recovery (e.g., remanufacturing) into the metric. *(Linder, Sarasini, & van Loon, 2017)*

ii. An estimation on the average product life span is included in the index. "This constitutes a judgement call (...) inconsistent with unambiguous methodological principles." *(Linder et al., 2017)*

2.0 Cradle to Cradle certification framework

The Cradle-to-Cradle Products Innovation Institute developed a C2C certification standard that provides designers, manufacturers and consumers information about a products sustainability measure. The standard performs impact assessments on a products materials and manufacturing practices based on five key principles: Material Health, Material Re-utilization, Renewable Energy Use, Water Stewardship, and Social Responsibility, and awards one of four certifications: Basic, Silver, Gold or Platinum *(Linder et al., 2017)*.

Product certification criteria are the same for all product types and any product or material sold to consumers are eligible to apply for this certification. The certification does not however apply to people, businesses, buildings, or processes *("MBDC | Cradle to Cradle Design," 2012)*.

This certification provides a good insight for designers and manufacturers on how to continually improve their products and manufacturing processes, by setting a guideline to implement the Cradle to Cradle framework "which focuses on using safe materials that can be disassembled and recycled as technical nutrients or composted as biological nutrients" *("MBDC | Cradle to Cradle Design," 2012)*.

Drawback of the indicator:

i. The standard has a broad focus which hinders the acceptance of it as a metric for circularity.

ii. The Material re-utilization assessment principle fails to account for different types of materials, cycles and components. *(Linder, Sarasini, & van Loon, 2017)*

3.0 Remanufacturing Product Profiles (REPRO)

Remanufacturing product profiles is a tool for measuring product circularity and performs statistical analysis on the End of Life scenarios of a product, based on 82 criterion's. "REPRO allows designers to compare their products with others that have been successfully remanufactured with a view to improve remanufacturing rates." *(Linder et al., 2017)*

Drawback of the indicator:

i. In terms of circularity, the tool has been weakly implemented as reuse and recycling measures are not considered.

ii. REPRO has a focus on improving re-manufacturing rates, however, it does not actually measure this. *(Linder et al., 2017)*

4.0 Life Cycle Assessment

"Life cycle assessment is a technique for assessing the environmental aspects associated with a product over its life cycle" *("Life Cycle Assessment - an overview | ScienceDirect Topics," n.d.)* Life cycle can be defined as "the consecutive and interlinked stages of a product or service system, from the extraction of natural resources to the final disposal" *("Life Cycle Assessment - an overview | ScienceDirect Topics," n.d.)*.

An LCA study consists of four stages:

Stage 1: The scale of the assessment is defined based on the part of product life cycle that needs study.

Stage 2: This stage comprises of an inventory with descriptions of "all material and energy flows within the system and especially its interaction with environment, consumed raw materials, and emissions to the environment" *("Life Cycle Assessment - an overview | ScienceDirect Topics," n.d.)*.

Stage 3: An environmental impact assessment is conducted based on the inventory created in stage 2. "The indicator results of all impact categories are detailed in this step; the importance of every impact category is assessed by normalization and eventually also by weighting" *("Life Cycle Assessment - an overview | ScienceDirect Topics," n.d.)*.

Stage 4: The final stage comprises of an interpretation of the results against the objectives defined in stage 1.

Drawbacks of the indicator:

i. LCA's can be costly and time consuming due to its strict guidelines, especially when introducing new products.

ii. Increasing the circularity measure may be a method to reduce externalities, however, this indicator does not specifically address circularity *("Life Cycle Assessment - an overview | ScienceDirect Topics," n.d.)*.

5.0 The Circular Economy Toolkit (CET)

The Circular Economy Toolkit is an assessment tool available freely, to identify and improve a product's circularity. The assessment tool consists of 33 questions sub-divided into 7 categories, namely: Design, manufacture and distribution; Usage; Maintenance and repair; Reuse and redistribution; refurbishment and remanufacturing; Product-as-a-service; and product recycling at the end-of-life. The questions are in a trinary format- yes/partly/no or high/medium/low *(Saidani, Yannou, Leroy, & Cluzel, 2017)*. The user interface of the tool is seen in Figure 13.0.

Drawbacks of the indicator:

i. The assessment tool lacks support for data construction

ii. The Circular Economy Toolkit does not provide guidance on product circularity improvements

(Saidani, Yannou, Leroy, & Cluzel, 2017)

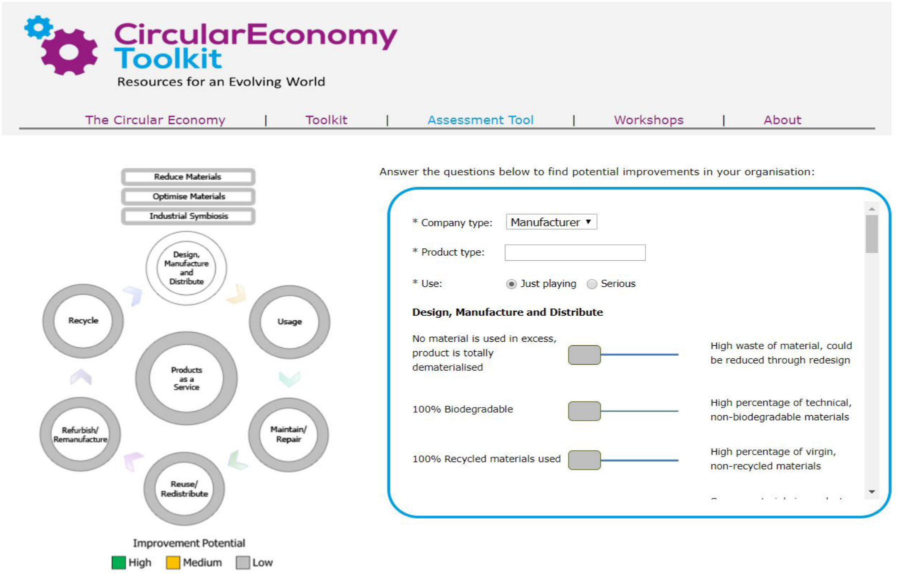


Figure 13.0 Interface of online Circular economy toolkit assessment tool *("Circular Economy Toolkit," n.d.)*

7.0 Overview

The assessment methods elaborated so far are related to a product's performance within the circular economy and is therefore compared for a better understanding (*Analysis, 2018) (Saidani, Yannou, Leroy, & Cluzel, 2017).*

Metric	Material circularity indicator	Cradle to cradle certification	Re-manufacturing product profiles	Life cycle assessment	Circular economy toolkit
Description	Circular transition for companies are facilitated.	Provides an insight for designers and manufacturers about product performance and processes.	REPRO conducts statistical analysis on the End-of-life of products	The environmental impact of a product is assessed over its complete lifecycles	Circular improvements to products as suggested
Platform support	Excel spreadsheet	Certification			Dynamic web page
Inputs	Material type, origin and end destination information in percentages.	Bill of materials	Detailed information about the products	Processes of a product system during its lifecycles; Material and energy flows; Waste outputs	Information about Life cycle stages.
Outputs	A single score	Product score card of one of four levels: Basic, Silver, Gold or Platinum	Measurements of profiles according to evaluated criteria	Evaluation of environmental impacts at each stage; commendations for improvement	3 level circular improvements for each category

Table 6.0 Overview of product performance assessment methods

8.0 Disassembly potential *(Elma Durmisevic, 2006)*

“Disassembly potential is defined as the ability of a building’s structure to be selectively taken apart with the intention of reusing and up-cycling some (or all) of its constituent parts.” *(Durmisevic, Ciftcioglu, & Anumba, 2003)*

E. Durmisevic developed a conceptual knowledge based model for assessing the disassembly capacity of a building and/or its systems. It is understood that if a building can be de-constructed safely and efficiently, then it has the potential to be greatly circular, as most of its constituent parts can be either reused or recycled, and here lies the importance of this indicator. Deconstruction is based on two key indicators – independence and exchangeability. Based on these indicators, The Disassembly Potential can be categorized into:

i. Category 1: Low disassembly potential
Independence and Exchangeability have values less than 30% of their best value.
ii. Category 2: Medium disassembly potential
The two indicators have between 30 and 70% of their best value.
iii. Category 3: High disassembly potential
The two indicators have above 70% of their best value.

According to this indicator, the following performance indicators are used to evaluate the disassembly capacity of a building or system:
(a)Functional Decomposition; (b)Clustering/Systematization; (c) Open versus closed hierarchy; (d) Base element specification; (e)Assembly sequences; (f)Interface Geometry; (g) Type of connection; (h) Life cycle coordination

These indicators are referenced and adapted in this research and is therefore explained in further detail :

(a) Functional decomposition:
Functional decomposition pertains to the design of flexible structures, which depends on the geometry of the component and/or its interfaces. The main aspects of functional decomposition are functional independence and systematisation of elements.

(i.i) Functional separation:
Functional separation can be of three types: Integration, incorporation and separation. The higher the level of functional separation within a component or product, the higher is the disassembly potential.

(i.ii) Functional autonomy:
Functional autonomy deals with the dependency between layers within a component, this can by either total integration, planned interpenetration, unplanned interpenetration or total separation (Figure 14.0).

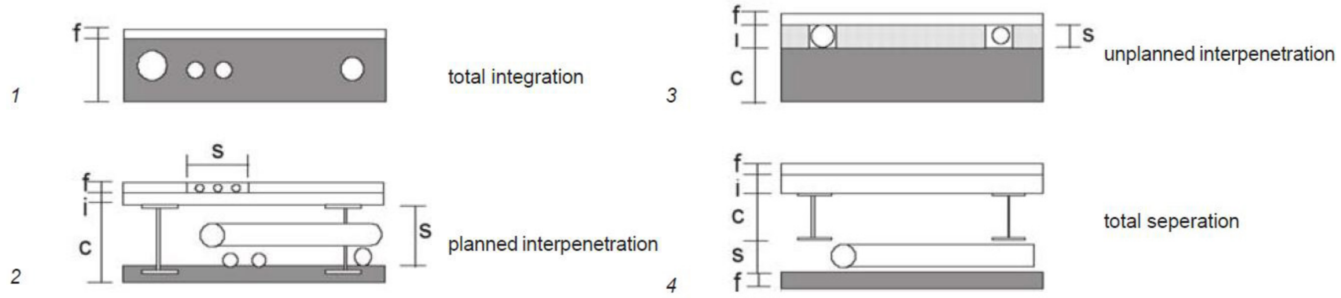


Figure 14.0 Different types of functional autonomy in a component. *(Elma Durmisevic, 2006)*

(b) Clustering / Systematization

Clustering or systematization refers to the assembly of single parts into a group. The method in which these assemblies are formed determines the disassembly method of the same, and this aspect has a large impact on the reusability of products are the end of life. Three aspects have to taken into account while determining the assembly system:
(1) Relational pattern, (2) Type and position of relations, (3) Base element specification

(c) Open versus closed hierarchy and (e) Assembly sequence

This parameter measures the relations within the building. Six types of relations are possible in a building, which determine the level of integration applied within a building and thereby the ease of disassembly at the end of life of the element. Two of the assembly types are illustrated in Figure 15: namely Symmetric assembly and Parallel assembly. Out of the two, a parallel assembly is preferred. This means that the element with lowest life cycle is placed at the top of the configuration so that it may be easily replaced without damaging the other elements which have a higher life cycle. These configurations may be horizontal or vertical, which also makes a difference. A horizontal configuration is static, as it has large interdependencies between elements, while a vertical configuration is considered more dynamic and is therefore better preferred.

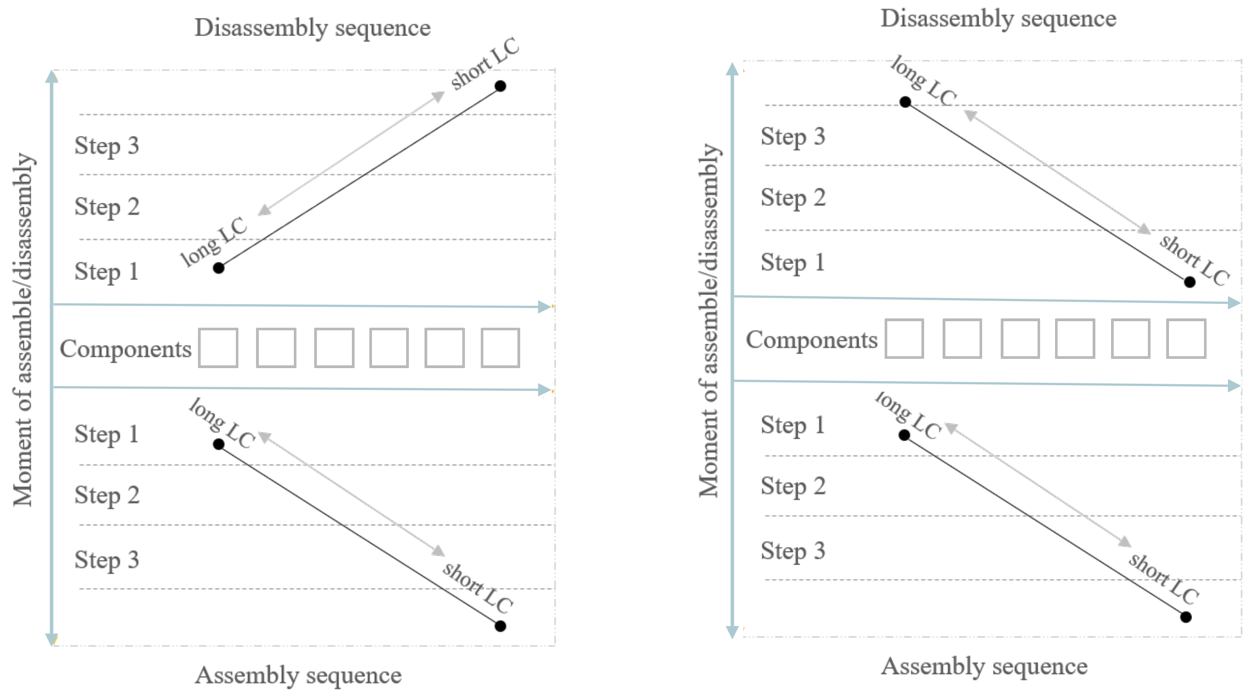


Figure 15.0 (left to right) Symmetrical assembly/disassembly sequence, Parallel assembly/disassembly sequence. *(Elma Durmisevic, 2006))*

(d) Base element specification:

In line with the ideology of assembly sequence, a base element is considered as an essential part of a configuration as it provides a high level of independence within sub-assemblies of a component. Theoretically, multiple elements are connected or related to this base element (which has a long life-cycle) therefore removing the need for elements within sub-assemblies to be related to each other. This ensures that in-case of repair or maintenance of an element, other elements within the assembly are not affected.

(e) Interface geometry

This parameter is used to understand and assess the edges of the product. In order to facilitate smooth or easily disassembly an open-linear geometry is preferred.

(f) Type of connection

Three main connection typologies are defined in the Disassembly potential by Elma Durmisevic. These are: Direct connections, Indirect connections, and filled connections.
For a highly flexible, adaptable and disassemble system, indirect connections are preferred as they incorporate screws and other dry accessories that have minimal intervention within a material. Direct connections create complete integration of elements, for instance overlapping joints that make it harder to take apart. Filled connections involve a chemical adhesive or material such as glue and is considered irreversible.

(g) Life cycle coordination

This parameter assesses the manner in which elements with different life cycles interact with each other.
As explained in the assembly sequence, elements with short lifecycle should be assembled last so that they can be easily replaced or maintained without hindrance to the other materials. The assembly sequence also determines the disassembly sequence of these elements.

9.0 Adaptable building & Flex framework

The flex framework by Geraedts explores the adaptability capacity of a building based on a list of indicators according to the different building layers introduced by Stewart Brand (The Six S's concept). The adaptive capacity includes the characteristics of a building that keep it functioning through various changes in requirements *(Geraedts, 2016).* There are three main categories within these indicators that are most relevant to a circular building: Dimensioning, Connections and Miscellaneous (for aspects excluding the other two categories) *(Geldermans & Rosen-Jacobson, 2015)*. This assessment method is used to measure an aspect of the building and not the whole.

10.0 GPR Gebouw

GPR Gebouw is an assessment tool that can be used to measure the sustainability of new and/or existing construction, residential and non-residential. The sustainability is measured within five themes: Energy, Environment, Health, Quality of use and Future Value. The building is rated on a scale of 1 to 10 per theme based on the three pillars of sustainability: Planet, People & Profit. The per theme rating provides an insight into the improvement possible in each, therefore making it advantageous especially during the design stage *("About GPR software - GPR software," n.d.)*.

11.0 Roadmap Circular Land Allocation (By Metabolic)

Metabolic is a leading sustainability consultant, that has developed a roadmap for assessing the degree of circularity a building has achieved. The assessment method known as 'Roadmap Circular Land Allocation' was formulated in consultation with market actors in the field and external experts, and is an ongoing project that is constantly reviewed based on practical experience gained from tenders, transformation, renovation and demolition projects *(Gemeente Amsterdam, 2017)*. This process is constantly bettering the roadmap is in line with Amsterdam's circular economy program – "learning by doing".

The basis of the roadmap is the four principles of a circular building:

i. Reduce: By reducing the demand of materials, energy or other valuable resources as the first measure, the subsequent steps to be taken for achieving a circular building become easier. It should be noted that, the reduction of demand should not threaten human comfort or the quality of life.

ii. Synergize: After reducing the demand, the local sharing of resources and residual streams within the building and immediate surrounding should be explored. This method is cost effective and produces efficient results. It should be noted that, locally available resources and raw materials available in the immediate surrounding of a building should be taken into account in the design phase of the building

iii. Supply: Once the demand has been reduced, and residual flows have been synergized, the remaining demand should be aimed to be supplied by renewable or sustainable sources.

iv. Manage: Receiving feedback on the systems makes it possible to ensure its smooth and efficient running.
(Gemeente Amsterdam, 2017)
These principles were developed into specific objectives and applied to six circular building themes, namely: Materials, Energy, Water, Biodiversity and Ecosystems, Human culture & society and Health & Wellbeing, Ultimately 32 criteria's were formulated based on which a building can be assessed or tender for circular building can be made. These are seen in the following table:

Strategies	Principles	Sub-strategies	Priority given by experts
Materials	Reduce	M1: Optimal material use	High (essential)
	Synergize	M2: Reutilization of products	High (essential)
	Supply	M3: Circular materials	High (essential)
	Manage	M4: Knowledge development and sharing	High (essential)
Energy	Reduce	E1: Minimize energy consumption	Medium
	Synergize	E2: Optimize energy demand	-
	Supply	E3: Sustainable and local energy	-
	Manage	E4: Knowledge development and sharing	Medium
Water	Reduce	W1: Minimize water consumption	-
	Synergize	W2: Water cascading	-
	Manage	W3: Knowledge development and sharing	Medium
Biodiversity and ecosystems	Reduce	BE1: Avoid the loss of biodiversity	-
	Synergize	BE2: Integration of ecosystem services	-
	Supply	BE3: Stimulate local biodiversity information	-
	Manage	BE4: Knowledge development and sharing	Medium
Human culture and society	Reduce	HS1: Avoid the loss of unique cultures and social diversity	High (essential)
	Synergize	HS2: Facilitate shared amenities and services	-
	Manage	HS3: Knowledge development and sharing	Medium
Health and wellbeing	Reduce	HW1: Avoid toxic materials and pollution	-
	Synergize	HW2: Ensure sufficient quality of life by providing an optimal indoor environment	-
	Manage	HW3: Knowledge development and sharing	Medium

Table 7.0 Metabolic's roadmap indicator for assessing a circular building *(Gemeente Amsterdam, 2017)*

2.3 CONCLUSION

The conducted literature study provides an understanding of concepts, tools, regulations and limitations in the realm of energy efficiency and circularity in the built environment. This can be used as a base for the analysis and design task to follow. A summation of the key lessons learnt according to the specific research questions are listed below.

i. What are the currently used design methods and tools to create a high energy performance building?

The design and realization of an energy efficient building or building with high energy performance involves a combination of many strategies. The four factors on which it depends are *(Access, n.d.)*:

- Passive solutions: Relating to the quality of materials and construction solution of the external wall of a building
- Active solutions: Technical installations of a building, such as sources of acquiring, producing, distributing and using energy efficiently.
- Operation & Maintenance: The manner of using a building and its resources
- Feedback & Monitoring: Systems of automation and control of all technological installations of a building, and systems of technical management in a building

Various tools can be used to assess the efficiency of the building and installed system depending on the output required, such as: Energie-Index Enorm, Uniec or Dynamic simulation tools (Trnsys, Design builder, Honeybee).

ii. What are the currently used design methods and tools to create a building within the circular economy?

Circularity in the built environment is under development and while the concepts are simple to understand, its practical application still has some setbacks to be dealt with. Design methods and tools to achieve a circular building vary between consultants, companies and nations. Some of the design tools to understand and realize circularity are:
a) Six S's
b) Cradle to Cradle
c) The Triple Bottom line
d) Life Cycle analysis
e) The New stepped strategy

The extent to which a product, component, company or building has achieved its circularity goals can be assessed by using the following tools:
a) Material Circularity Indicator
b) Cradle to Cradle certification framework
c) Re-manufacturing product profiles
d) Life Cycle assessment
e) The circular economy toolkit
f) The circular economy indicator prototype
g) Disassembly Potential
h) GPR Gebouw
i) Roadmap circular land allocation

A review of the above mentioned design strategies and assessment tools reveal the absence of an assessment method that wholly combines the varied aspects related to the energy generation and use of a building, and the circularity of a building in terms of the other resources in a building for instance water and material use. Using the existing assessment tools, these aspects can be individually assessed however, their impact on one another cannot be determined. Thus, in this research a framework for this assessment will be developed, which can be used to pinpoint the synergies and trade-offs in a building due to design decisions made with respect to the energy performance and/or circularity of a building. And in doing so, the combined circular performance of a building can be improved.

REFERENCE PROJECTS

03

This section answers the following sub-research question:
3. Which approaches or measures are used in reference projects having both high energy performance and circular ambitions?

Aim of research: As stated in the problem statement, the extent to which a building is both energy efficient and circular is unknown, as the boundary conditions of circularity aren't strictly defined. A study of reference projects will give an insight on what methods are defined as contributing to the goal of energy efficiency and circularity. This information would thereby provide a base for understanding the present gap and how this can be improved.

Chosen projects: De Ceuvel and Schoonschip

3.1 DE CEUVEL, AMSTERDAM

3.1.1 GENERAL INFORMATION

De Ceuvel is a former industrial plot converted into a sustainably planned workplace for creative and social enterprises. Established in 2012, the plot is located in Amsterdam North, and is leased out for 10 years by a group of Architects with the aim to turn the site into a regenerative urban oasis.

The heavily polluted site consists of 15 office spaces in the form of retrofitted houseboats, placed on the land, and is surrounded by soil-cleaning plants. This project incorporates many innovative and sustainable solutions that cater specifically to the plot and the available soil type. For instance, due to the temporary nature of the project, the houseboats are provided with dry composting toilets and individual biofilters for grey water treatment, instead of a connection to the sewer system *("TKI Loop-closure Cleantech Playground," 2016)*.

3.1.2 OVERVIEW OF CIRCULAR MEASURES

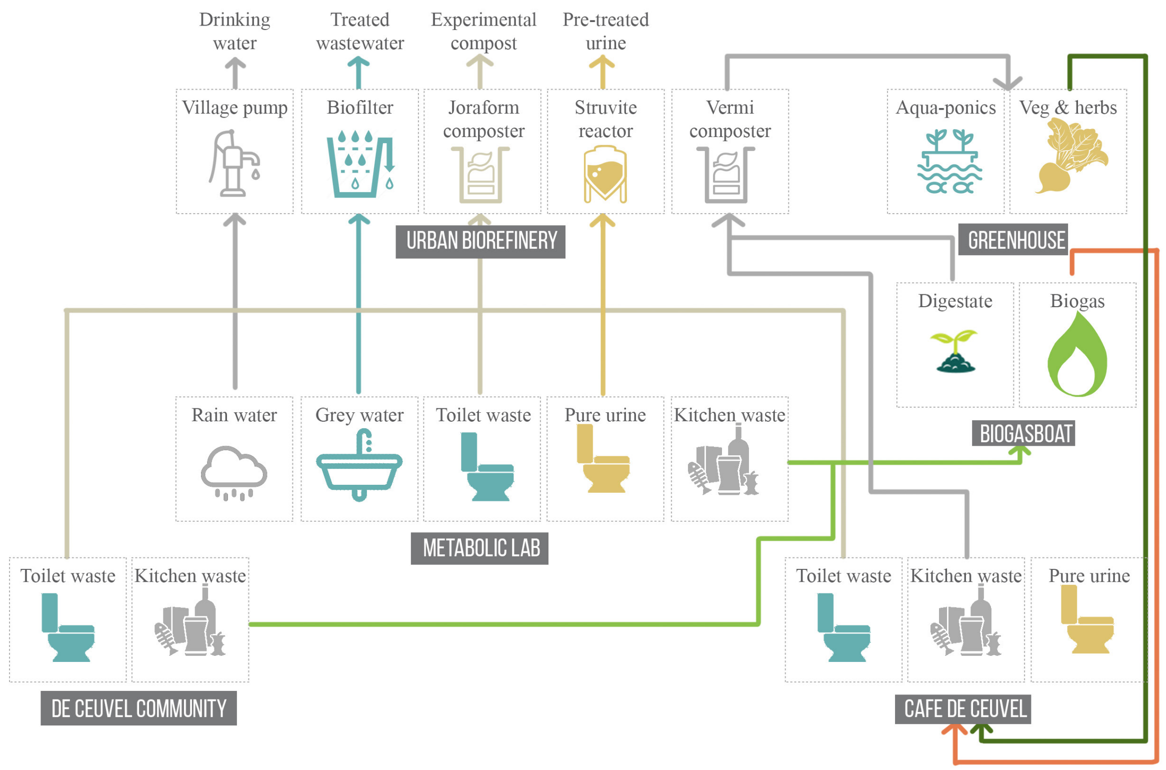


Figure 16.0 Overview of sustainable measure incorporated in the project *(Adapted from "General Information – De Ceuvel," n.d.)*

The following measures have been incorporated in de Ceuvel (seen in Figure 16.0) with the aim to create high quality cycles for the generated waste:

i. Compost toilets: Waste is collected through compost toilets in the houseboats and brought to a tumbling composter for further processing. The solid waste produced in the toilets are used as fertilizers.

ii. Heat Exchanger: A heat pump and air-to-air heat exchange ventilation system is fitted in each office boat, capturing 60% of the heat and circulating it back inside. This technology circumvents the need for a gas connection and therefore promotes the use of renewable electricity to power the boat.

iii. Helophyte Filters: Wastewater from the office kitchen sinks are processed in a decentralized helophyte filtration system placed adjacent to each boat and discharged into the ground.

iv. Struvite reactor: Nutrients from urine is recovered by using a struvite reactor and then combined with other local inputs to be used as a fertilizer.

v. The Biogas boat: This technology is under development. By this, the boats can convert organic waste into biogas through a biodigester, to be used for cooking.

vi. Up-cycling: The development is built largely out of recycled materials.

vii. Aquaponics greenhouse: The greenhouse produces vegetables for an on-site café using a close-loop aquaponics system.

ix. Grey water recycling: Grey water is treated in individual low-tech biofilters.
("TKI Loop-closure Cleantech Playground," 2016)

3.1.3 OVERVIEW OF ENERGY SYSTEM

De Ceuvel is a completely electric site (except for some stove heating), achieved through the use of solar panels, heat pump and other innovative technologies, such as the following:

i. Over 150 PV panels are installed on the office boats, generating 36,000 kWh of power annually, meeting the heating demand of the on-site systems, and a part of the remaining demand. A green energy supplier delivers energy to meet all other demands.

ii. The boats are fitted with an air-air heat pump and a heat exchanger ventilation system, allowing for 60% of waste heat to be recovered and reused in the boats.

iii. The boats are designed to reach near-passive house standards with increased daylighting and LEDs to reduce electricity demand. The energy consumption of the boats are measured using sensors and provide feedback.

iv. The performances of the water-related technologies are monitored and evaluated. "Self-sufficient neighbourhoods with their own, decentralized water supply add to the image of the circular economy."
("TKI Loop-closure Cleantech Playground," 2016)

Overview of energy systems installed on site, and their production:
Total Power consumption (for 15 boats): 113,7 MWh/yr
Total Heat consumption (for 15 boats): 115,2 Mwh/yr

The following issues were/are faced in the project owing to the all-electric system:

i. The total power production is only 23% of the total power consumption due to poor solar panel performance.
ii. Generated heat cannot be stored in the air-to air pump, to meet future demand.
iii. The system is highly dependent on grid energy.
(For, n.d.)

3.2 SCHOONSCHIP, AMSTERDAM

3.2.1 GENERAL INFORMATION

The Schoonschip project is located in Buiksloterham and has been chosen as a reference project as it is a CPO project planned within the same energy efficiency and circular principles as the projects to be analysed in this research.
The neighbourhood consists of homes for 46 households and a community center on 30 floating plots. The first of the water homes will be realized in 2018, and by 2020 the remaining will be realized. Schoonschip began as a foundation and was joined thereafter by a CPO of all the households, run by individual inhabitants of the neighbourhood ("Schoonschip – Amsterdam," n.d.).

3.2.2 OVERVIEW OF ENERGY & CIRCULAR MEASURES

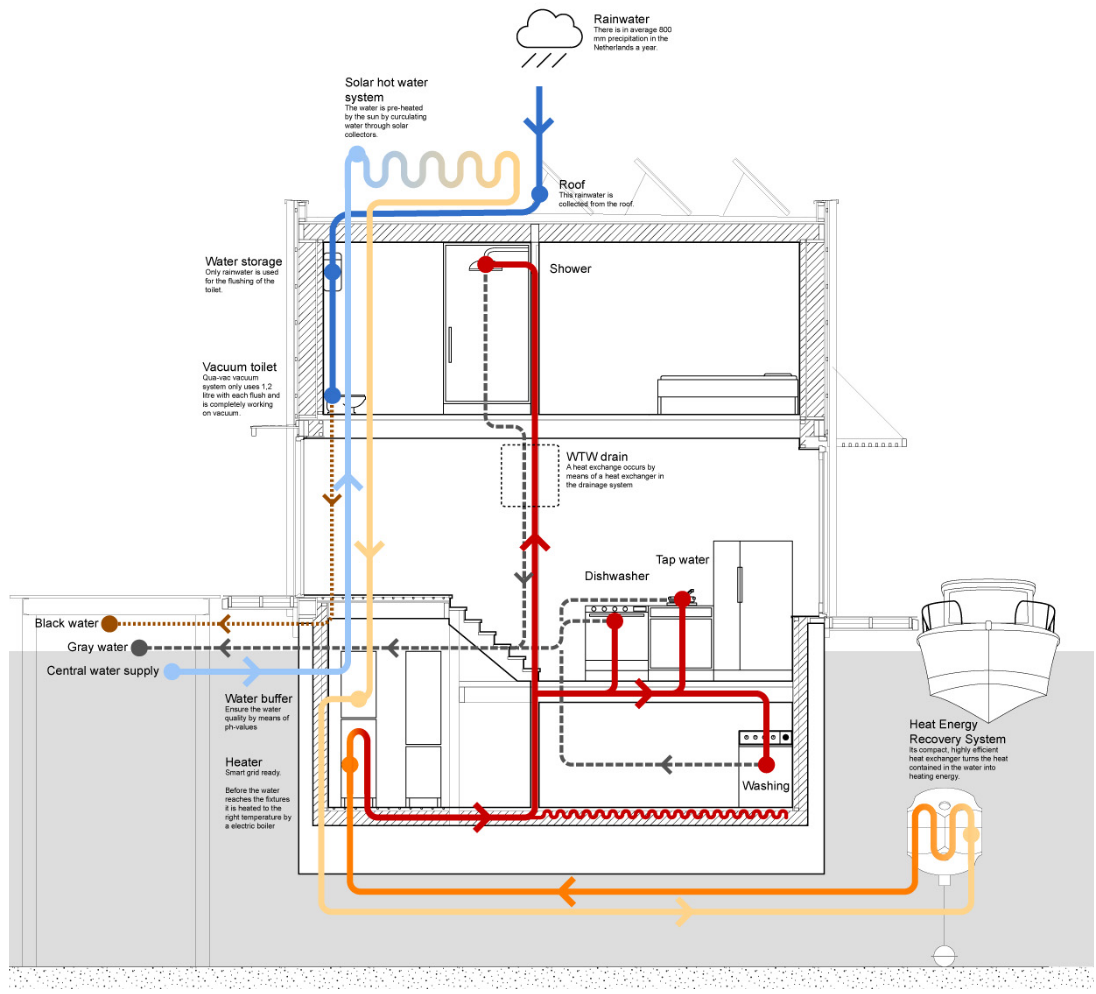


Figure 17.0 Overview of sustainable plan for houseboat 9 in the project *("Schoonschip — spaceandmatter.nl," n.d.)*

The section of a typical household in the Schoonschip neighbourhood, seen in Figure 17.0, shows some of the sustainable measures incorporated to meet the ambitions set in Buiksloterham. It is further explained as follows:

i. The homes are designed to be well insulated (EPC = 0) and avoid a connection to the natural gas network.
ii. Waste heat from showers are recovered using a recovery system.
iii. Electricity is produced by photovoltaic solar panels and every household is/will be fit with a battery to store surplus energy.
iv. Energy is shared between households, through a communal smart grid.
v. Vacuum toilets are installed in the houses so that grey and black water can be collected and processed into biogas.
vi. One-third area of the roofs are green roofs.
vii. Smart devices and ICT applications will be used to optimize the yield and facilitate the exchange of self-generated energy.
ix. Space heating and domestic hot water demands are met by a water-to-water heat pumps that extracts water from the canal.

Overview of energy systems installed on site, and their production:
Total Power consumption (for 46 houses): 252,6 MWh/yr
Total Heat consumption (for 46 houses): 402,6 Mwh/yr

By installing battery system, the houses store a large fraction (approximated at 65,7%) of the on-site generated energy. Despite Schoonschip's high energy ambitions, it only produces 50% of its electricity demand and is quite an expensive system to be installed individually, therefore cannot be directly applied or suggested for the case study.

3.3 CONCLUSION

3. Which approaches or measures are used in reference projects having both high energy performance and circular ambitions?

De Ceuval and Schoonschip are two projects with high energy performance and circularity ambitions. The projects are located in Amsertdam North, which is the same area as the assessed case studies and is therefore is suitable as a reference.

De Ceuval has an all electric system that runs 15 office spaces in the form of retrofitted houseboats, placed on land. Many innovative and sustainable technologies have been applied in this project at a neighbourhood scale facilitating sharing of resources and waste.

In this project, the interesting feature is the reuse of waste that takes place in order to minimize discarding of output as much as possible, such as the following:
a. Rainwater is collected and converted to drinking water through a cleaning system and received at a village pump.
b. Kitchen waste from the community and cafe are turned into biogas to be used for cooking.
c. The raw vegetables for the cafe kitchen are grown on site in a greenhouse, housing an aquaponics chamber fed by composted kitchen waste and digestate from the biogas boat.
d. Urine from toilets is treated in a struvite reactor and used as fertilizer.
e. Grey water from sinks go through a biofilter, and reused as wastewater in the community.
f. An air-to-air heat pump captures 60% of the ventilation waste heat. According to a study conducted by Metabolic, this circumvents the need for a gas connection and therefore promotes the use of renewable electricity *(For, n.d.)*.

In terms of energy performance, a drawback that was noticed in the project is low power production of the PV panels, possibly due to shadowing. My understanding from this drawback, is the need to implement a series of systems that can be used in cascade, incase there is a shortage or low performance in the main system. This was further reinstated during the assessments conducted on new buildings in Buiksloterham, as one of the cases uses such a cascading system to ensure the house can depend on only renewable energy generated on-site.

The second reference project studied is Schoonship, located in Buiksloterham. The 46 households and 1 community centre are positioned on 30 floating plots.
One particular household in the neighbourhood has the following sustainable measures incorporated:
a. Grey water and black water collected from homes are treated in a bio-refinary to produce biogas.
b. Shower heat recovery systems reuse waste heat
c. The demand for space heating and domestic hot water is met by a water-to-water heat pump (using canal water)
d. The homes are well insulated to have an EPC = 0, and is not connected to the natural gas network
e. Energy is shared amongst households through a communal smart grid.
f. Households are fit with a battery for storing excess produced electricity, to be used later.

However, this project has faced a few setbacks as well. Although it has high energy ambitions, it only produces 50% of the electricity it uses on site. Overall the energy system is also quite expensive and is not ideal for replicating in other projects.

INTEGRATED ASSESSMENT METHOD

04

This section answers the following sub-research questions:
4. How can the energy performance and circularity of buildings be assessed in an integrated way?
a. What is the data needed for the assessment of energy performance and circularity of new buildings?

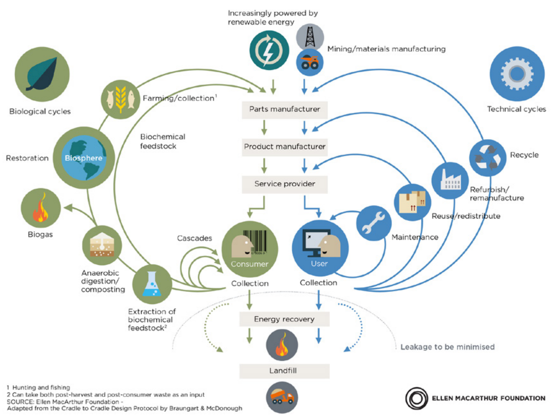
Aim of research: A literature review of the existing assessment tools in place to analyse a building design revealed the absence of one that conducts an integrated assessment, using which synergies and/or trade-off's between design decisions can be known. The availability of such a tool would provide information on improvement areas within a building, tackling which can raise its combined circular performance.

4.1 FRAMEWORK

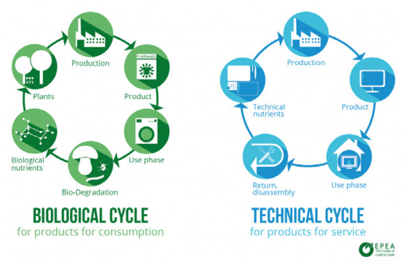
4.1.1 OVERVIEW OF EXISTING FRAMEWORKS

The studied concepts, design strategies and assessment methods have varying degrees of usefulness in the development of the integrated assessment method. Figure 18.0 is a graphical overview of the methods, and of these the most relevant concepts/design strategies (to this study) are further explained with an emphasis on the factors taken into account in the development of the integrated method.

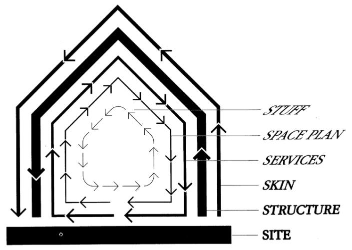
1. Frameworks:



(a) Ellen MacArthur foundation

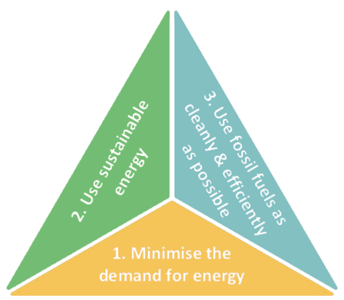


(b) Cradle to Cradle

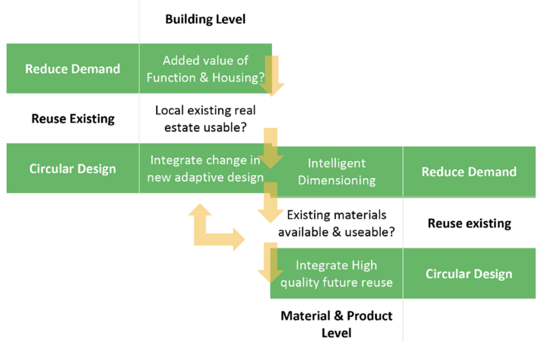


(c) Shearing layers

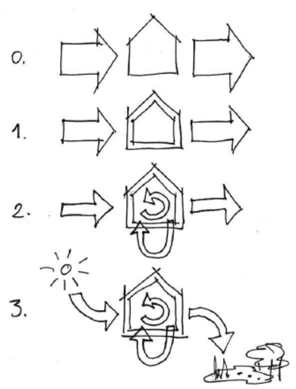
2. Design strategies:



(d) Trias Energetica



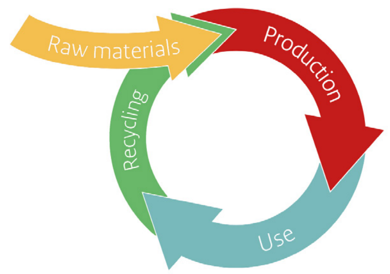
(e) NSS circular adaptation

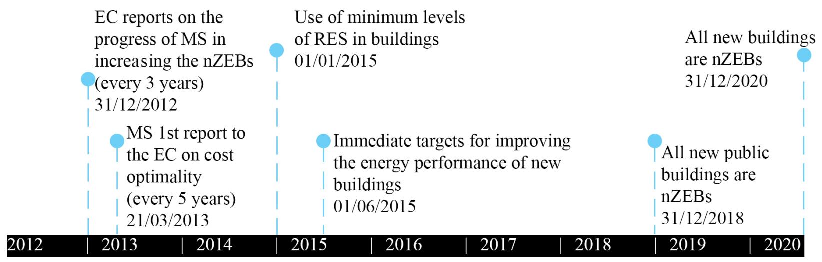


(f) New stepped strategy

Figure 18.0 Overview of frameworks and design strategies reviewed

3. Legislative:





(g) Circular economy ambition (h) EPBD target

Figure 18.1 Overview of legislative frameworks reviewed

Cradle to Cradle by Michael Braungart and William McDonough, shearing layers by Stewert Brand, The new stepped strategy by Andy van den Dobbelsteen and its circular adaptation by Bob Geldermans and Laura Rosen-Jacobson are applicable to the integrated framework and are therefore further explained:

Cradle to Cradle: The cradle to cradle philosophy identifies material flow in two cycles: Biological and technical. A biological material can be returned to nutrients at the end of life to be reused in new product manufacturing. This is a circular approach to material use. Technical materials are not treated in the same manner, and need to be used and maintained in an efficient manner so that it can be continuously cycled at a high quality.

The New stepped strategy (NSS): NSS proposes a cradle to cradle outlook at the Trias Energetica method, and lays out the following steps:
1. Reduce the energy demand in the first instance.
2. Reuse waste streams produced within and nearby the building site
3. Produce the energy required for remaining demand by renewable sources of energy
4. Leave waste that can be used as food

NSS circular adaptation: While the energy performance of a building can be measured and evaluated based on set norms and standards, the rules of circularity is still under development. We should take this into consideration while evaluating a product, component or building. This is proposed in the circular adaptation of the new stepped strategy. For instance, if a building component uses 2X materials instead of X, in order to achieve air tightness, it can be regarded as an increased environmental load. However, if these materials are assembled and connected in a manner by which at the end of technical life of the component, the materials can be fully harvested at a high quality and reused without much treatment, the material use should be considered circular. NSS explores this interpretation of the new stepped strategy.

Steps of the New stepped strategy (NSS) Circular adaptation:
1. Reduce demand
2. Reuse existing

3. Circular design – Integrate high quality future adaptive reuse (at material and product level) and change in new adaptive design (at building level)

Shearing layers: A building is divided into six layers, and each of these layers have a different use life and replacement frequency, as seen in Figure 19.0

The six layers are:
1. Site – which is permanent.
2. Structure – the building itself.
3. Skin – an integral part of the building, that could potentially undergo changes due to a shorter lifespan of components.
4. Services – Subject to change or repair, and has a much shorter lifespan than the structure.
5. Space plan – Dependent on design and typology of houses.
6. Stuff – Dependent on user's choices.

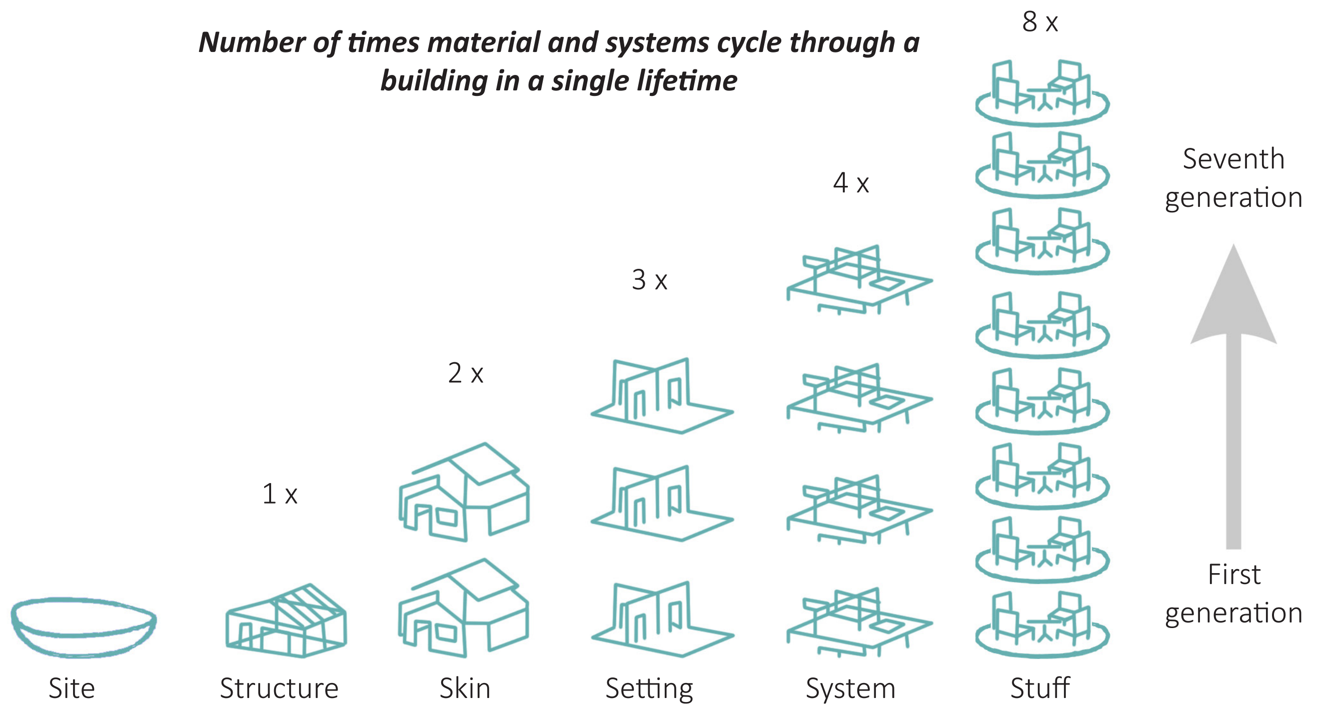


Figure 19.0 Different shearing layers and its transformation potential during building life *(Anne-Marie Rakhorst, www. du-urzaamheid.nl)*

4.1.2 SYSTEM BOUNDARIES IN TERMS OF ENERGY

In this research the building site has been chosen as the boundary. The building site refers to the plot within which the building is situated. A boundary condition allows for the specification of the various flows considered and not considered in the framework. Firstly, there is a distinction made between energy and material flows, and secondary, the energy and material flows are further categorized for inclusion in or exclusion from the framework.

According to the EPBD recast definitions, all energy flows except electricity for household appliances and outlets must be included in the calculation for nearly zero energy buildings. Taking this as a general scope for the energy assessments in the framework, this refers to all systems that consume energy to perform the following functions within the building:
a. Space heating
b. Domestic hot water heating
c. Cooling
d. Summer comfort
e. Air movement i.e. fans
f. Lighting
(BREEAM UK New Construction, 2014)

In terms of energy, this research creates a boundary around the net delivered energy to a building as opposed to the primary energy, to attain a more accurate representation of the energy needed and used in a building.
"The energy used by the building 'technical systems is from delivered energy to the building or from on site renewable energy (without fuels)" *(Kurnitski et al., 2015)*.
Externally delivered energy can be defined as the primary energy from external sources minus the transmission and conversion losses of the system. To attain the total delivered energy to a building site, the electric energy from renewable sources on site is added to the delivered energy from external sources.

Within this boundary, the externally delivered energy in the form of electricity, heat and cold enter the building's technical systems for energy use and production. A fraction of this energy is lost in transmission and conversion, and another fraction maybe is exported back to the grid. The remaining energy from external sources along with on-site production from renewable sources represents the net energy need. This energy is supplied to the building for heating, cooling, ventilation, domestic hot water, lighting and appliances, in addition to the solar heat gains/ losses through the building envelope.

Figure 20.0 is a representation of all the energy flows within a building. According to the new stepped strategy by Andy van den Dobbelsteen, there must be a reuse of internal waste within the building in order to move towards a sustainable built environment. In terms of energy, this can be interpreted as reuse of waste heat within a building, such as shower or ventilation heat. This is an important flow and is taken into consideration in the framework as it leads to reduced net energy need during the operational phase of the building.

Summing up Figure 20.0, within the chosen boundary, the inputs required for the building's technical systems is externally delivered energy and on-site renewable energy without fuels, of which a fraction is (i) reused internally, (ii) exported back to the grid and (iii) released as emissions. The remainder equals the energy need of the building.

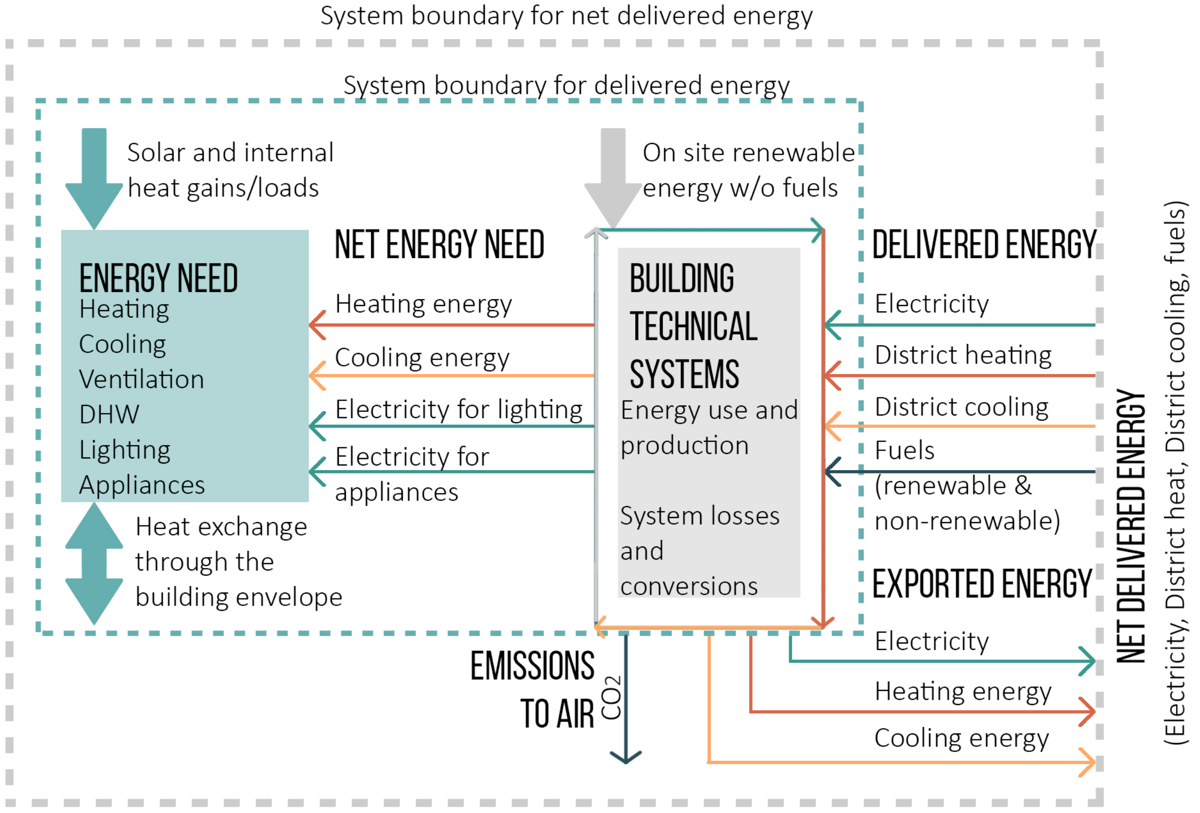


Figure 20.0 System boundary in terms of energy (Adapted from *(Kurnitski et al., 2015)*)

4.1.3 SYSTEM BOUNDARIES IN TERMS OF CIRCULARITY

From the literature review it is concluded that within the chosen boundary, two material types are identified: Technical and Biological. The technical cycle of a product undergoes the following cyclic transformation path:
Production- Product- Use phase- Return/disassembly- Technical nutrients.

And, the biological cycle of product undergoes the following cyclic transformation path:
Production- Product- Use phase- Bio-degradation- Biological nutrients- Plants
("Accreditation by EPEA - Cradle to Cradle CertifiedTM certification and more," n.d.)

However, for a technical and/or biological product, only the use phase of the product or material falls directly within the system boundary. The sourcing, mining and manufacturing of the product is carried out externally, and the same applies to the phase after the use phase. At the end of life of the product, it is disassembled and returned to either the service provider, product manufacturer or parts manufacturer for cycling, and unless the material is maintained, reused or recyled for use in the building, these processes lie outside the chosen system boundary. These flows have been aptly represented diagrammatically by the Ellen MacArcthur Foundation and Cradle to Cradle philosophy (Figure 18.0).

To sum this up, the material flows that fall directly within the system boundary are the inflow of manufactured materials/ products and the outflow of materials/products that have reached the end of use life/ technical life.

4.1.4 SCOPES AND LIMITATIONS

The design, operation and demolition of a building involves various other flows apart from the ones explained thus far. The following energy flows have a direct correlation with the material use in a building, however they have been excluded from this research:

1. Transportation energy: On-site energy installations/systems are transported to the building site from a manufacturing plant. Taking a step further back, the materials involved in the manufacturing is sourced and transported from beyond the manufacturing location, while the exact origin of these materials can be assumed, it cannot be guaranteed. Therefore, the energy required for materials and products are not studied in this research.
2. Demolition energy: Demolition energy represents 1% of the total life cycle energy of a material (or product) and is not considered in this research, as the research is conducted for new buildings in the operation phase *(Crowther, n.d.)*.
3. Recurrent energy: Energy installations have a technical life span shorter than that of a building, implying the need for periodic maintenance, repair and replacement. These activities translate into the periodic need for sourcing and production of materials for use in the energy systems, and the energy involved in this process is known as recurrent energy. This flow is not studied in this research as the replacement frequency of buildings in their early operational phase cannot be precisely known.

Similarly, the following properties of materials have been excluded from this research:

1. Cost of materials: Material, component and system choices are not limited to its circularity potential, and are often also based on the investment costs which is subject to user preferences. This is beyond the scope of this research.
2. Recycling: The energy required for recycling of materials/components/products is not taken into account in this research. At the end of life of the building, it is proposed that if demolition leads to production of reusable products, the building benefits as there is value retention.

4.1.5 INTEGRATED ASSESSMENT FRAMEWORK

A schematic representation of the framework for an integrated assessment of energy and material flows within the system boundary is depicted in Figure 21. 0.
The framework is divided into three aspects: Resources – comprising of elements that are brought to the building site to be utilized for design and/or operation of the building; The building site – within which the different flows combine and cascade over the use life of the building; Output – comprising of all usable and unusable elements that leave the building site (to be returned or not).

As this research aims to understand the extent to which a building is circular (material use in combination with energy performance), the processes outside the system boundary must be acknowledged to a certain extent as well. As explained in Section 2.1.3, the operation of an energy efficient building is dependent on the green behaviours of the consumers and not merely the design or construction. In a similar manner, in order to create and maintain a circular building, users must be aware of the sourcing and end of life possibilities of the materials that go into their buildings so that a positive change can be instigated. For instance, while it can be said that an energy installation or system comes pre-assembled to the building site, therefore the design of the installation does not fall within the context of the study. Rather, only the manner in which the installation is fixed and used on site, the decision to choose a PV panel or any other energy installation should depend also on the circularity of the product itself. By this it is ensured that product manufacturers take responsibility in the circular manufacturing of a product rather than just safe disposal, which is the case currently with PV panels especially. There are guidelines in place about the correct method to recycle a panel therefore reducing the quantity of waste produced but there is no norm on how to produce the product to minimize environmental load/impact in the first place. This is why in terms of system boundary of material flows, the material properties and design of the energy installations are also considered although their production is outside the building site.

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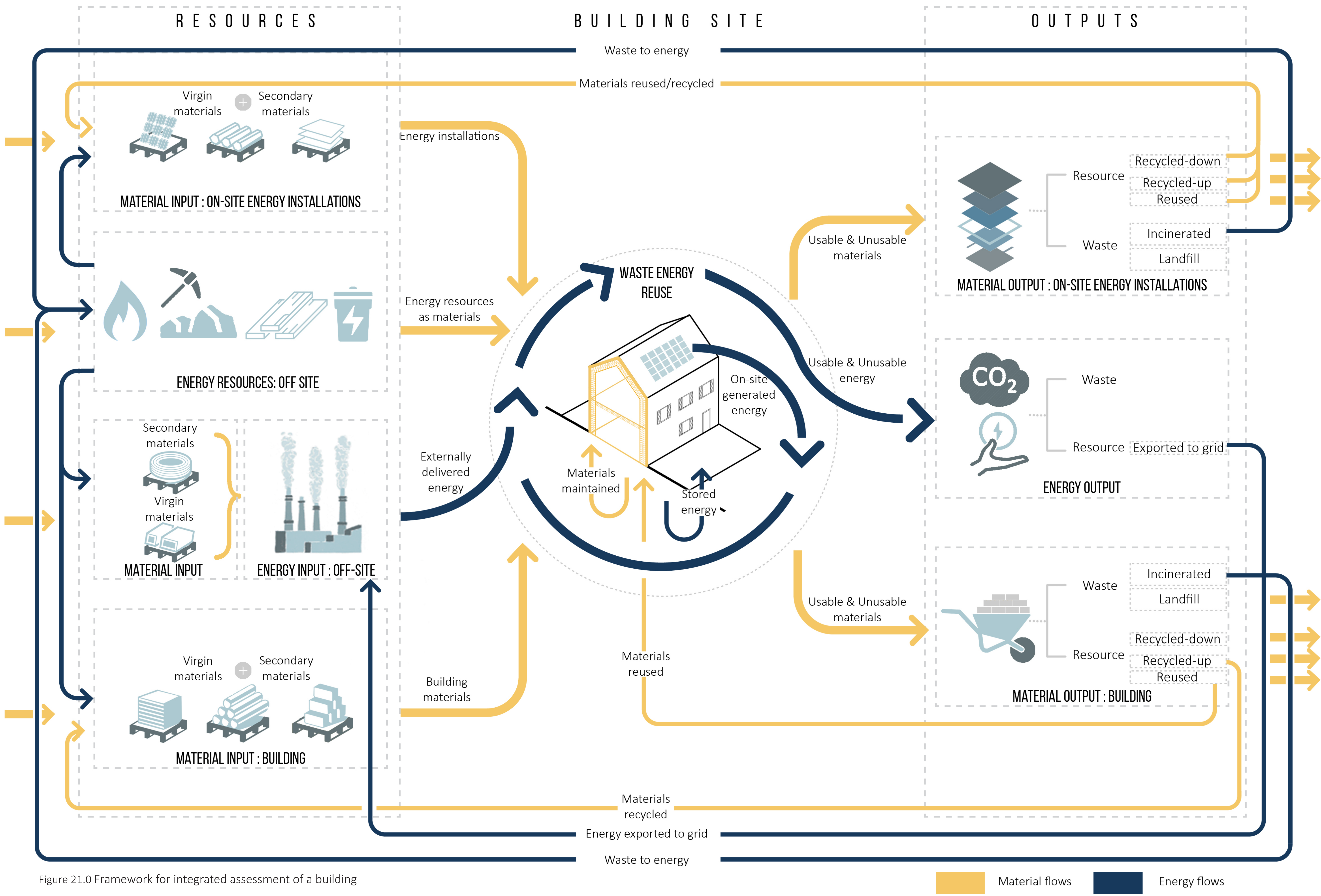


Figure 21.0 Framework for integrated assessment of a building

Resources:

Resources that are required for and utilized by the building have been denoted in the framework. This extends to resources required for the functioning of energy systems in the building and functioning of the building itself. Explicitly these are: the materials used for construction of the building; externally delivered energy and the consequent materials and energy resources required for its production; and the materials used in on-site energy installations. The on-site generation of energy (thermal + electric) is also essentially a resource utilized by the building, however, it is a resource that falls within the building site and is denoted in this manner in the framework.

The terms externally delivered energy and on-site generation were covered in Section 4.1.2. The term energy resources refer to the materials or resources that are combusted to produce this energy (heat/electricity). Off-site energy installations requires a constant feed of such resources, which currently comprise of renewable and non-renewable resources. Some of these resources may be categorized as materials and flow into the building's site for use in on-site installations (e.g. Wood as a resource for wood boilers in the building). Apart from the energy resources that flow in the building as materials; the framework term 'material input' comprises of virgin materials that are unprocessed in nature, and secondary materials, which have been utilized previously.

A further distinction is made between the types of material input required based on the technical life of the materials. An initial material input is considered to be the amount of material utilized for a function during 0 – X years (X= technical life of the component). In the case where the use life of a building (Y) is > X, an additional material input is required for Y- X years. However, an additional material input could also be required during 0- X years or Y- X years, in case of repair or damage. The summation of the periodic and non-periodic inputs equal the material input for a building / on- site energy installation.

Reuse / Cascades:

Cascade utilization can be a flow of considerable size, and is accounted for within this framework in the form of energy reuse, material reuse and recycling *(see 'Definitions' section for difference between reuse and recycling).* The process of material recycling is conducted in two pathways – leading to either upcycled materials or downcycled materials. Upcycling refers to the addition of value to a material to increase its use life, while downcycling refers to cycling of a material after lowering of its original or intended quality. Here a distinction is made in the form of cascade allowable within the confines of a circular building. In order to consider and account for the next cycles of a product or material, provisions for high grade reuse of resources should be an integral part of the design of a circular building. This translates to the materials/products being utilized keeping in mind their biological and/or technical cycles, so that it is possible to return these materials to their original cycles. Essentially the materials should be cycled more than once, and this is where a bottleneck with downcycling arises. By downcycling a material, the quality of the valuable content is reduced, which firstly, limits the number of times the material can be cycled. Secondly, does not align with circular economy principles as the material cannot be returned back its original form. However, upcycling is considered a circular practice as the biological or technical composition of the material itself is not altered, which means the material can be cycled multiples times in various high quality forms.
Another form of cascade that remains in place within the building site is called 'materials maintained'.

It must be noted that the materials used in these cycles must be non-toxic and healthy to begin with. The high quality cycling of a hazardous material does not fall within the confines of a circular economy.

Outputs:

There is a periodic outflow of usable and unusable materials, and energy from a building. Service systems (energy installations) have a shorter life span as compared to the structure of the building, therefore there is a recurrent output from these systems. Here, the life of a building is considered equal to the life of the structure, as interpreted from Stewart Brand's concept of shearing layers. According to Figure 19.0, if the life of a building structure = 1, the services in the building are replaced 4 times, or the life of systems = 1/4. Similarly, the skin of the building is replaced 2 times. It cannot assumed that all outputs have reached end of life if released from a building. A distinction is made between outputs that are resources (usable/re-usable), and outputs that are waste.

In this framework, waste is interpreted as residues that are discarded or reduced to their lowest quality by the process of incineration. The output of incineration can be reused as an energy resource (waste to energy) which acts as an input for off-site energy systems. While it can be argued that these outputs should then be considered as a resource, as some form of reuse is better than no form of reuse, referring back to the definition of a circular building, resources should be cycled at their highest quality and therefore the incineration of resources to produce waste is not considered a circular practice.

In terms of resources, not all material output equals directly reusable resource. Two types of resources are identified, that leave the boundary of the building. The types are defined as follows:

Reused materials: "Materials that can be extracted from the waste streams and used again without further processing, or with only minor processing, that does not alter the nature of the material (e.g. cleaning, cutting, fixing to other materials)" *(BREEAM UK New Construction, 2014).*

Recycled materials: "Materials diverted from pre-consumer and/or post consumer waste streams that require significant processing before they can be used again" *(BREEAM UK New Construction, 2014)*.

a. Recycled – up (Upcycling) : "Reuse (discarded objects or material) in such a way as to create a product of higher quality or value than the original" *("upcycle | Definition of upcycle in English by Oxford Dictionaries," n.d.).*
b. Recycled – down (Downcycled) : "to create an object of lesser value from (a discarded object of higher value)" *("Downcycle | Definition of Downcycle by Merriam-Webster," n.d.)*.

Output also refers to the energy output released from a building. This can further be categorized into waste and / or resource. To reiterate the previously mentioned aspect about waste; waste here refers to carbon emissions and waste heat that is unused or low quality residue of the input resource. It can be reused after processing, however this is not deeply analysed within the scope of this research.
To assess the circularity of new buildings based on energy and material flows, these flows have been developed as indicators, and are further discussed in the next chapter.

4.2 DETAILED INDICATORS

4.2.1 OVERVIEW

The three aspects of the framework namely, Resources, Reuse/cascades and Outputs are developed into indicators in order to quantify each of the flows and determine the overall degree of circularity designed into the case study buildings.

The indicators are :

IN 1: Energy input (delivered & on-site generated)
IN 2: Material input (on-site energy installations) + Energy resources
Material input (building)
IN 3: Energy reuse
IN 4: Energy output
IN 5: Material output (on-site energy installations)
Material output (building)

4.2.2 SCOPE OF ASSESSMENT

As mentioned in section 4.1.2, a boundary is created around the net delivered energy to building systems. This refers to all systems that consume energy to perform the following functions within the building are included:

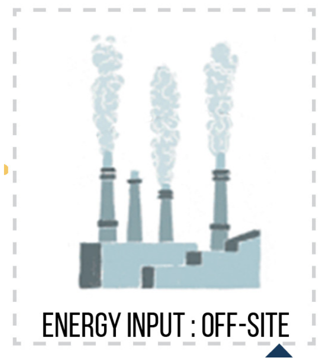
- Space heating
- Domestic hot water heating
- Cooling
- Summer comfort
- Air movement i.e. fans
- Lighting

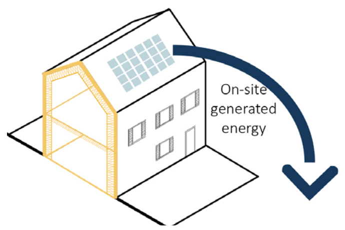
For the material flows, in addition to the material input required for creating on-site energy installations that cater to the above systems, the calculations extend to the different layers of a building.

4.4.2 INDICATOR 1 : ENERGY INPUT (EXTERNALLY DELIVERED & ON-SITE GENERATED)

1. Description :

As elaborated in Section 4.1.2, the energy input of a building may either be delivered from off-site sources, generated on-site by renewable sources, or both. This indicator quantifies each of these inputs.





2. Relevance:

By determining the energy input utilized for building related needs, i.e., heating, cooling, ventilation, lighting and domestic hot water, the share of energy externally delivered of generated by renewable sources can be determined. An energy efficient or high performing building should ideally have an optimized energy demand, with renewable sources generating the required energy demand. From a circular point of view, there should be minimal to no dependence on fossil fuels/non-renewable sources.
It must be noted that an energy efficient building must be a combination of renewable production and reduced demand although in the framework only the energy used is studied. Energy demand within the building is directly proportional to the energy delivered to the building, therefore reducing the demand reduces the quantity of energy delivered to the building.

3. Data required for calculation:

- Quantity of externally delivered energy (kWh/year & kWh(th)/year)
- Quantity of On-site generated energy (kWh/year & kWh(th)/year)
- Source of on-site generated renewable energy
- Usable area of the building (m^2)

An example of the required data:

	Energy carrier	Source	Quantity (kWh/ year) OR (kWh(th)/ year)
Delivered energy	Electricity	Electricity grid	10.000
	External heat for heat or hot water	District heating	10.000
	Fuels- Renewable (wood, biomass)	Neighbourhood generator	10.000
	External cooling supply	District cooling	10.000
	Energy carrier	Source	Quantity (kWh/ year) OR (kWh(th)/ year)
On-site generated energy	Electricity	PV panel	10.000
	Heat	Solar collectors	10.000
	Cold	Passive cooling	10.000

Table 8.0 Example of data input for Indicator 1

4. Calculation for the indicator:

1. On-site renewable energy per m^2 (kWh/m^2/year) = On-site generated energy (thermal+electric)/ Usable area of the building (m^2)
2. Delivered energy per m² (kWh/m^2/ year) = Delivered energy (thermal+electric)/ Usable area of the building (m^2)

5. Desired outcome :

- Within the spectrum of energy input, the share of energy from renewable sources should be higher than non-renewable / essentially there should be no dependence on non-renewable sources.
- More renewable energy is generated by the building on its site, than delivered externally.

6. Impact on other indicators :

Material input (on-site energy installations & building) :

1. To maintain the efficiency of on-site energy generation, the installations have to be periodically maintained/ replaced, which translates to a recurrent input of material.
2. In order to reduce the total energy input required, the building has to be efficiently designed in such a way that the energy demand is lowered. Many factors contribute to this, as seen in the literature study (Section 2.1.3), one of which is tightening the building's envelope (within reason) leading to an increased material input.

4.2.3 INDICATOR 2 : MATERIAL INPUT (ON-SITE ENERGY INSTALLATIONS & BUILDING)

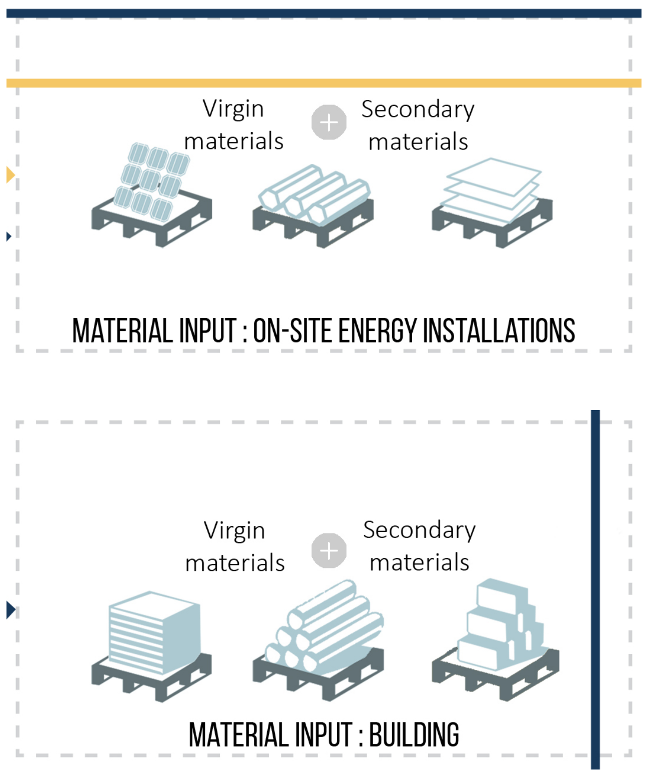
1. Description :

This indicator assesses the quantity of materials utilized in the various building layers and on-site installations.

2. Relevance :

For on-site energy installations: While increasing the share of on-site generation of renewable energy in a building is a circular move, the installations used to do the same is material intensive, and may incorporate scarce materials that are harmful for the environment. By gathering data on the systems, a circular change can be instigated.

In terms of the building: The process of material selection for building construction is partly governed by the energy demand reduction achieved by the material. Often, a higher amount of material use leads to a greater demand reduction, however this increased environmental impact has to be compensated by ensuring the material can be cycled indefinitely while maintaining a high quality.



3. Data required for calculation:

- The composition, thickness, area and weight(kg or kg/m^2) of the used materials per component/ building layer.
- Intended use life of the element/component/material (in years)
- Technical life of the element/component/material (in years)
- Assembly sequence of the element and connection type between materials

Example of required data:

Building Layer	Component Layer	Sub-Layer	Material description	Density (kg/m^3)	Thickness (m)	Area (m^2)
Structure	Ground floor	Structure	Hollow reinforced concrete	10	1	10
		Insulation	EPS	10	1	10
		Finish	Cement screed	10	1	10

Table 9.0 Example of data input for Indicator 2

4. Calculation for the indicator:

Step 1: Determine the environmental load (= MPG score) of system or building layer.
This can be calculated by any MPG software that incorporates Nationale Milieudatabase
Example: MRPI – MPG software

Step 2: Determine initial material use of the system/ building layer:

This can be done using the following formulae:
Initial material use (kg) = Density of the material (kg/m^3) x Thickness (m) x Area (m^2)
Additional material use (kg) = Density of the material (kg/m^3) x Thickness (m) x Area (m^2)

Step 3: Determine if material can be easily replaced in the composition, and calculate additional material input (kg) in the following manner:

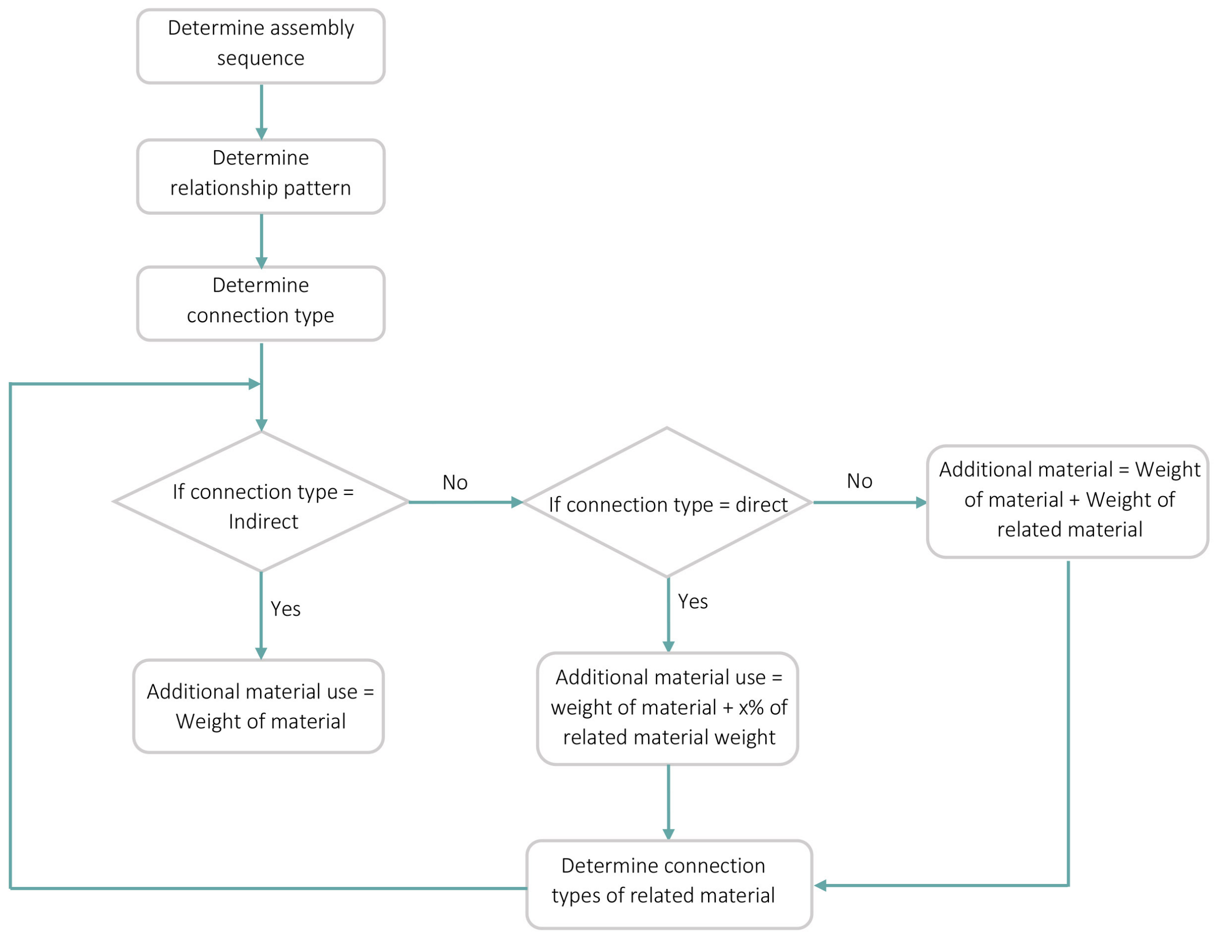


Figure 22.0 Flowchart to run sequence to determine additional input of a material/component/product

The types of connection details have been referenced from Elma Durmisevic's Disassembly potential, and is as follows:

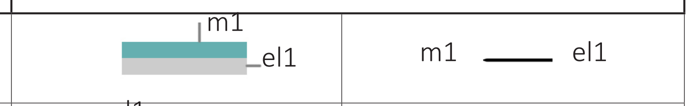
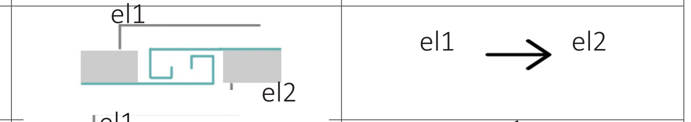
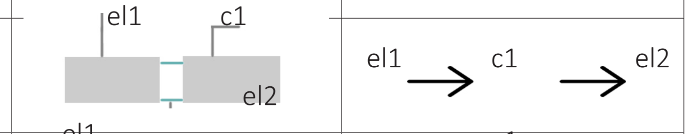
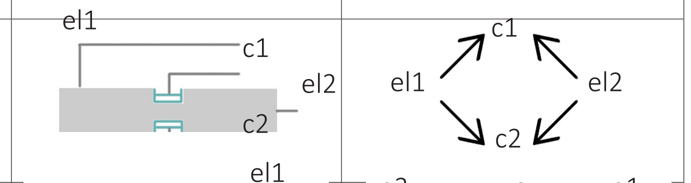
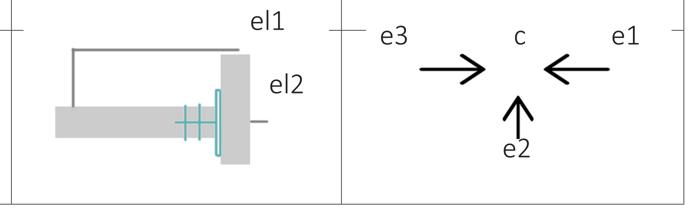
Type of connection	Reuse-ability / Recyclability	Dependence in assembly
Filled connection	No reuse / No recycling	
Direct connections between two pre-made components	No reuse / No recycling	
Direct connection with additional fixing devices	Reuse & recycling is restricted	
Indirect connection via dependent third component	Reuse & recycling is restricted	
Indirect connection via independent third component	Yes reuse / Yes recycling	
Indirect with additional fixing device	Yes reuse / Yes recycling	

Table 10.0 Types of connection details *(Elma Durmisevic, 2006)*

5. Calculation example:

Step 2: Determine the initial material use of each building layer:

Building Layer	Component Layer	Sub-Layer	Material description	Initial material input (kg)	Frequency of replacement (use life/ building life)	Additional material input (kg)
Structure	Ground floor	Structure	Hollow reinforced concrete	X	1	= X
		Insulation	EPS	Y	5	= 5Y
		Finish	Cement screed	Z	15	= 15Z

Table 11.0 Example of data input for Indicator2

Step 3: Determine if material can be easily replaced in the composition, and calculate additional material input(kg)

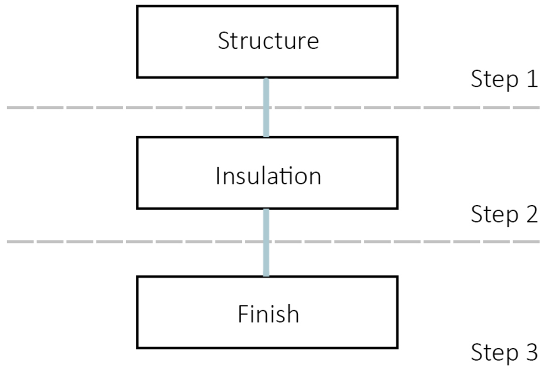


Figure 23.0 Assembly sequence and relationship pattern of the building layer

Building Layer	Component Layer	Sub-Layer	Connection type			Additional material input (kg)
			Structure	Insulation	Finish	
Structure	Ground floor	Structure		Indirect via independent third component		= X + 5Y +15 Z
		Insulation	Indirect via independent third component		Filled connection	= 5Y +15 Z
		Finish		Filled connection		= 5Y + 15Z

Table 11.1 Connection type and concluded additional material input (kg)

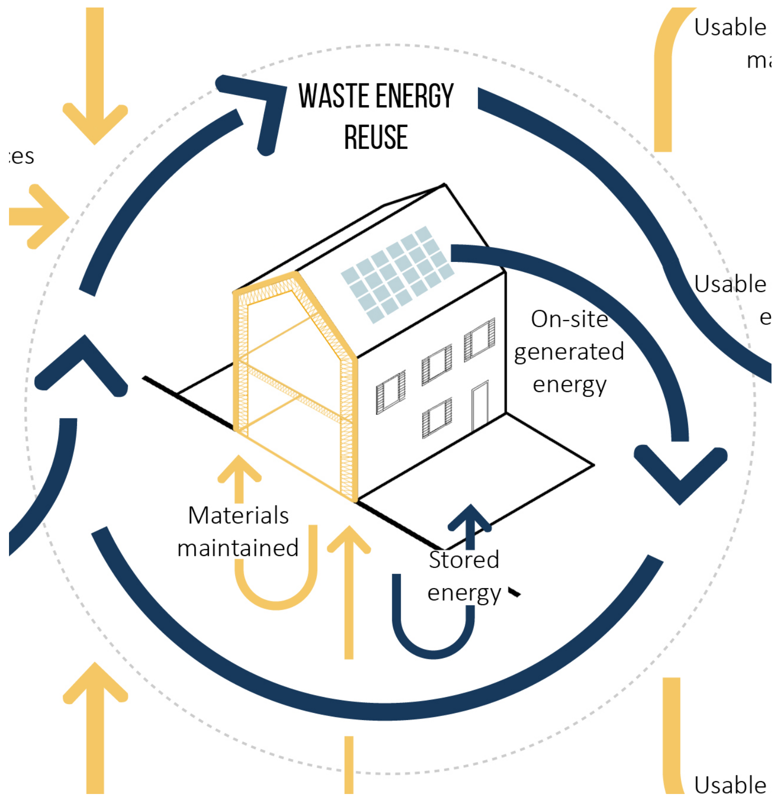
6. Desired outcome :

1. Maximize the use of secondary and renewable materials (that have a sustainable origin) while maintaining the desirable quality of the product.
2. The quantity of material going into the building should be governed by one of the following two aspects:
   Where material reusability is limited, the quantity of material input should be controlled. Materials unnecessary for the function should be avoided as much as possible.
   Where intelligent dimensioning of the material leads to high quality theoretical reusability of the material, increased material input should be encouraged.
3. Match technical durability and use durability to have minimum environmental impact.
4. Avoid the use of toxic or hazardous material; select materials with relatively low environmental impact.

7. Impact on other indicators :

Energy input : As stated in Indicator 1, the material input for energy installations is directly proportional to the quantity of renewable energy produced on site.
In terms of the building, until a certain limit the energy input and building material input are indirectly proportional. Which means for example, by increasing the thermal mass of a building, the energy demand of the building is reduced, translating to reduced overall energy input. After a point, increasing the material input does not significantly reduce the energy demand.

4.2.4 INDICATOR 3 : ENERGY REUSE



1. Description :

"This indicator evaluates the application of the principles of energy cascading in the design of a building. With energy cascading, available energy streams are reused as far as possible, and efforts are made to maintain the quality by optimally matching the temperature and form (light, electricity or heat) to the end use." *(Gemeente Amsterdam, 2017)*

2. Relevance :

"In a circular economy, the high-value use of available streams in order to prevent wastage or loss of quality is important, and also in the case of energy streams where the focus is on high-value reuse of heat and available resources" *(Gemeente Amsterdam, 2017)*.

3. Data required for calculation:

• Quantitative data on types and amount of waste energy reuse (kWh/kWh(th))
• Amount of energy stored on site (kWh/kWh(th))

4. Calculation for the indicator :
For shower heat recovery:
• Recovered energy = 50% of energy demand for domestic hot water * return efficiency (%)

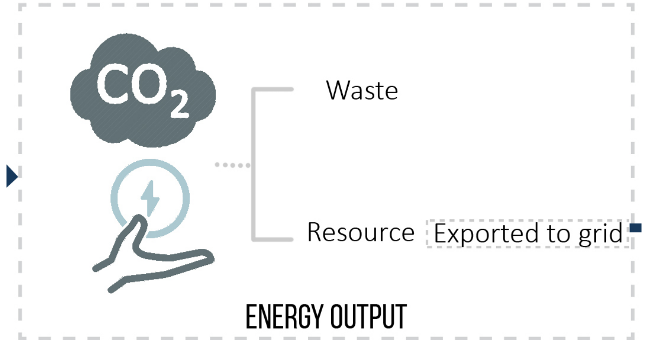
5. Desired outcome :

Facilitate and maximize reuse of internal waste energy to reduce energy delivered.

4.2.5 INDICATOR 4 : ENERGY OUTPUT

1. Description :

This indicator quantifies the energy output of a building in the form of surplus energy, unused waste heat and emissions.



2. Relevance:

Merely the efficient delivery or use of energy is not sufficient. While designing an energy system, the possibility to store energy for seasons of shortage or to return to the grid should be considered. In addition, unusable emissions should be minimized or mitigated as much as possible. As a principle, all outputs leaving the building must be usable. Within the realm of a circular economy, waste should be minimized or mitigated altogether.

3. Data required for calculation:

• Amount of energy exported to the grid (kWh/kWh(th))
• Total resulting CO2 emissions (kg)

4. Calculation for the indicator:

1. Qualitative assessment :Acknowledge the existence of surplus energy, either stored or returned to grid
2. Quantitative assessment : Determine the building's emission rate: Carbon dioxide emissions per m2 of usable area

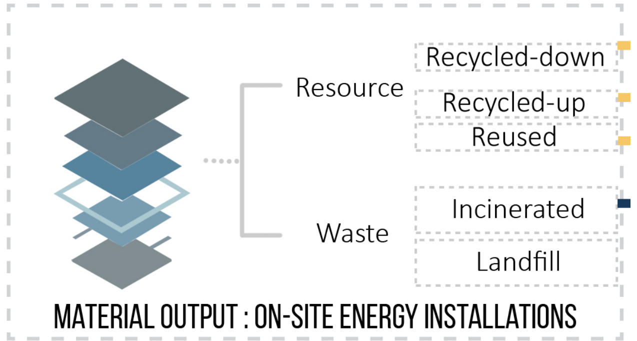
5. Desired outcome :

1. Aim to maximize the efficiency of on-site energy generation to have surplus energy that can be stored for use according to the demand.

4.2.6 INDICATOR 5 : MATERIAL OUTPUT (ON-SITE ENERGY INSTALLATIONS & BUILDING)

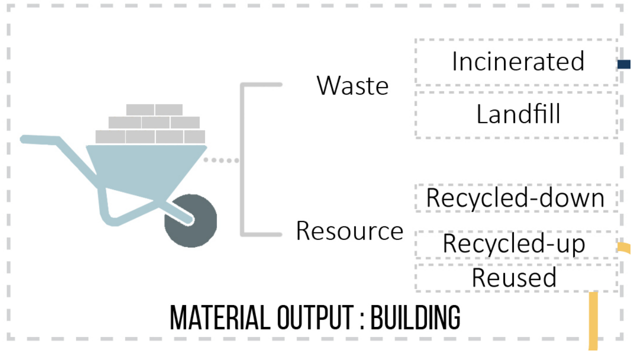
1. Description :

This indicator quantifies and categorizes the materials extracted at the end of use life of the product/element/component/building. The output can be categorized as either a resource (reusable/recyclable) or waste according to the end of life path designed or realized for the output.



2. Relevance:

In a circular economy, all materials must be cycled at their highest quality indefinitely.
Elements and components must therefore be designed and manufactured in such a manner that material reusability is facilitated.



3. Data required for calculation:

• Quantity of initial and additional material input *(calculated by Indicator 2 : Material input)*
• Intended use period of the material
• Chemical treatments/modification done to biological materials

4. Calculation for the indicator :

Step 1: The sequence of calculation of this indicator is identical to the sequence used to calculate the additional material input (refer to Indicator 2 : Material input). What is important to note is the sequence of assembly determines the sequence of disassembly: Sequence of disassembly is the reverse of assembling, therefore the consequences of replacing a material can be determined by this study.

An additional step to follow in this sequence is the following:

Step 1a. Chemical treatments done to the material and determine if the treatments are reversible or if they affect the reusability of the material.
Table 10.0 categorizes the output based on the connection type between materials according to Elma Durmisevic's Disassembly potential. *(Elma Durmisevic, 2006).*

5. Desired outcome :

1. Maximize the reusability potential of the material
2. Minimize demolition waste that is landfilled.
3. Ensure materials can return safely to either biological or technical life cycle after use-time without quality loss based on their life cycle in the following scheme:

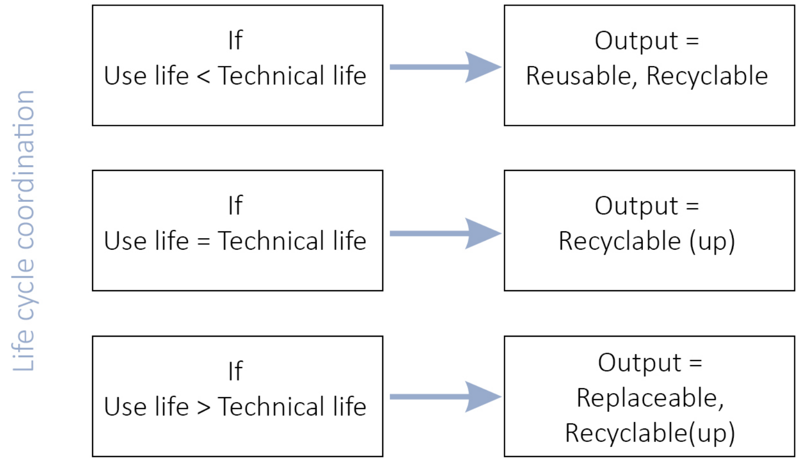


Figure 24.0 End of life categorization of a material based on life cycle (Adapted from (Durmisevic & Van Iersel, 2004))

6. Impact on other indicator :

Energy efficiency : Incorporating demountable connections between material layers increases the high quality reusability potential of the material. However a possible drawback is the creation of thermal bridges or air gaps that in turn affect the energy performance of the building.

4.2.7 EXAMPLE : SOLAR PANEL (ROOF)

The calculation of the indicators explained thus far will be demonstrated using a typical monocrystalline PV panel. A PV panel is chosen for this purpose due to its small scale yet complex material composition, making it ideal to especially demonstrate the calculation of the material flows.
**See appendix 12.1.2 for product catalogue (Trina Solar, 2015)*

INDICATOR 1 : ENERGY INPUT

Data Input :

BVO (m^2)	200
Usable area (m^2)	180
Type of solar cells	Monocrystalline 156 x 156 mm (6 inches)
Area of PV panels (m^2)	25
Peak power (watt)	265 Wp (one PV module)
Electrical energy generated (kWh)	0,8 (performance ratio) *265 *25 = 5300

Table 12.0 Data input for calculation of Indicator 1

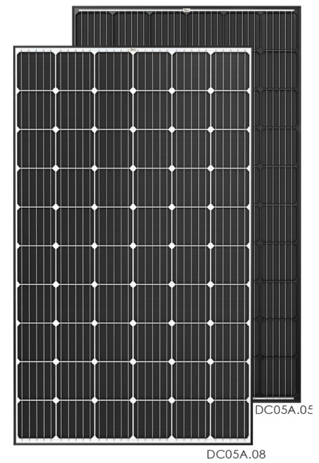


Figure 25.0 Trina Solar 'Honey module' monocrystalline PV

Calculation for the indicator :
On-site renewable energy per m^2 (kWh/m^2) = Energy produced on site (from renewable sources) (kWh) / Usable area (m^2)
On-site renewable energy per m^2 (kWh/m^2) = 5300 / 180 = 29,4 kWh/m^2

Conclusion: This indicator provides an understanding of the sources and quantity of energy used in a building. In this example as the PV panel is studied in isolation to the building, a conclusion on the degree of circularity cannot be drawn.

INDICATOR 2 : MATERIAL INPUT (ON-SITE ENERGY INSTALLATIONS & BUILDING)

Step 1: Determine the environmental load (= MPG score) of system or building layer.
Calculation method : MRPI-MPG software

MPG score for 25 m^2 of PV panels = 0,27
**See appendix A for calculation reference*

Step 2: Determine initial material use of the system:

For this PV panel the individual material inputs per m^2 is known. Using this, the total material input (kg) is calculated as Material input (kg/m^2) x Use area (m^2)

Energy supply source	Material description	Material composition (%)	Material input (kg/m^2)	Area (m^2)	Total material input (kg)
PV Panel	Solar cells – Monocrystalline	3,48	0,4	25	9,9
	Glass – AR coated tempered glass	74,16	8,5		211,4
	Frame- Anodized aluminium alloy	10,3	1,2		29,4
	Cables – Photovoltaic technology cable (usually standard 12V wire)	0,57	0,1		1,6
	Back sheet – White (DC05A.08); Black (DC05A.05)	3,6	0,4		10,3
	Junction box –Enclosure material – thermoplastic (IP 65 or IP 67 rated) ("IP67 THERMOPLASTIC POLYCARBONATE ENCLOSURE - Ip-65/67 Junction Box Manufacturer from New Delhi," n.d.)	-	-		
	Encapsulant- EVA	6,55	0,7		18,7
	Total initial material input				**284,5**

Table 12.1 Breakdown of Material specifications of a Monocrystalline PV panel *(IRENA, 2016)*

Step 3: Determine if material can be easily replaced in the composition, and calculate additional material input(kg)

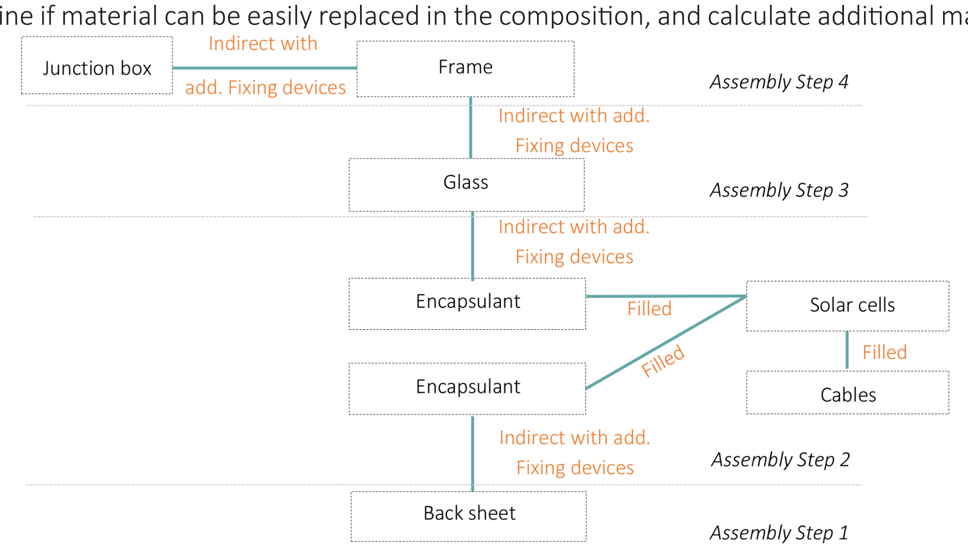


Figure 26.0 Assembly sequence and relationship pattern of a typical monocrystalline PV panel

Material / Element	Connection type: Junction box	Frame	Glass	Solar cells	Cables	Encapsulant	Back sheet	Additional material input (kg/m^2)	Additional material input (kg)
Junction box		Indirect with add. fixing devices	-	-		-	-	Wt. of junction box =	-
Frame	Indirect with add. fixing devices		Indirect with add. fixing devices	-		-	-	Wt. of frame = 1,2	29,4
Glass	-	Indirect with add. fixing devices		-		Indirect with add. fixing devices	-	Wt. of glass = 8,5	211,4
Solar cells	-	-	-		Filled	Filled	-	Wt. of solar cells+ cables+ EVA = 1,2	29,2
Cables	-	-	-	Filled		Filled	-	Wt. of solar cells+ cables+ EVA = 1,2	29,2
Encapsu-lant	-	-	Indirect with add. fixing devices	Filled	Filled		Indirect with add. fixing devices	Wt. of solar cells+ cables+ EVA = 1,2	29,2
Back sheet	-	-	-	-		Indirect with add. fixing devices		Wt. of back sheet = 0,4	10,3

Table 12.2 Analysis of connection types in a Monocrystalline PV Panel and resultant additional material input required

The circularity of 25 m^2 of PV panel based on the analysis in Table 12.0 is interpreted as follows:

Failure modes of a PV panel are generally attributed to defects such as (i) glass breakage, (ii)laminate or (iii) electrical defect and (iv) process losses *(IRENA, 2016)*.

(i) In case of glass breakage, the component can be taken apart easily to replace only the glass.

This is concluded based on its hierarchy in the assembly sequence, open relationship pattern and demountable connection type with other materials.
Therefore, the additional material input required for replacement of the glass = Weight of glass = 211,4 kg

(ii) In case of laminate defect such as discolouration, the encapsulant cannot be replaced without affecting the solar cells and cables.

The easy replacement of the laminate is hindered by its fixed connections to the solar cells. As the encapsulant is laminated in vacuum to the solar cells, which in turn has laid in electrical cables, in order to replace the encapsulant all three components will have to be taken out of the composition.
Therefore, the additional material input required for replacement of the encapsulant =
Weight of the encapsulant + Weight of solar cells + Weight of cables = 29,2 kg

If the connections between these components were reversible (encouraged in the circular economy), the additional material input would have been = only the weight of encapsulant = 18,7 kg
Thus, the degree of circularity is hence lowered by 29,2 - 18,7 = 10,5 kg.

(iii) The same analysis as laminate defect applies to electrical defects.

In this case, the additional material input required for replacement of the cables = Weight of the encapsulant + weight of solar cells + weight of cables = 29,2 kg

If the connections between these components were reversible, the additional material input would have been = Weight of cables = 1,6 kg
The degree of circularity is hence lowered by 29,2- 1,6 = 27,6 kg.

(iv) By process losses, the lowering of efficiency of solar cells is addressed.
The analysis followed in (ii) and (iii) also applies here.

In this case the additional material input required for replacement of the solar cells = Weight of encapsulant + weight of solar cells + weight of cables = 29,2 kg

If the connections between these components were reversible, the additional material input would have been = Mass of cells = 9,9 kg
The degree of circularity is hence lowered by 29,2- 9,9 = 19,3 kg.

INDICATOR 5 : MATERIAL OUTPUT

Step 1: The sequence of calculation of this indicator is identical to the sequence used to calculate the additional material input.
Step 1a. Determine connection types and chemical treatments done to the material:

Material / Element	Theoretical reusability according to connection type	Chemical treatment
Junction box	Reusable / Recyclable	Unknown
Frame	Reusable / Recyclable	Anodized
Glass	Reusable / Recyclable	Anti-reflective coating
Solar cells	Waste (Incinerated/ landfilled) OR Recycled (down)	Unknown
Cables	Waste (Incinerated/ landfilled)	
Encapsulant	Waste (Incinerated/ landfilled)	
Back sheet	Reusable / Recyclable	

Table 12.3 Categorization of material output

Conclusion :

Recycling plays a key role in the end of life of PV panels. It is estimated that without recycling, by the year 2050 there would be approximately 60 million tons of PV panel waste going to landfills. *("Recycling: A Solar Panel's Life after Death | GreenMatch," n.d.)* . The end of life scenario of individual components in a PV panel are as follows.

1. Frame : All external metals parts are reused.
2. Glass : According to research, 95% of the glass in the silicon-based PV panel is reused.
3. Solar cells : From the analysis, it is concluded that the cells cannot be reused or recycled directly. This is also proven by research: it is seen that the cells have to be etched and broken down to make new cells.
4. Cables : These may be regarded as waste during thermal processing with a fraction being reused, however the exact end of life is unknown.
5. Encapsulant : Due to its integration with the solar cells, the encapsulant is treated at 500C and evaporated off in order to access the cells. The remains of the encapsulant is used as a heat source for further thermal processing.
6. Back sheet : According to the analysis, the back sheet should be directly reusable or recyclable in new PV modules.

4.3 CONCLUSION

4. How can the energy performance and circularity of buildings be assessed in an integrated way?

A review of existing literature related to design concepts and strategies focussing on high performing building in terms of energy and circularity is the base for creating the integrated assessment framework. A strategy that wholly combines these two themes does not exist, therefore a combination of the New stepped strategy, its circular adaptation and Stewart Brand's shearing layers is the starting point of the assessment method. Each of these strategies have factors that are important to either of these themes, or both. Here theme refers to energy performance and circularity. The hypothesis is that by integrating these factors together, the important elements for both themes are combined in a way that is sufficient for an integrated assessment to enable a circular building life.
In the New stepped strategy, the factors related to energy are: (i) to reduce the demand of the building, (ii) reuse waste streams, (iii) to produce remaining demand from renewable sources, and (iv) have food as output.
In the circular adaptation of NSS, reducing demand of resources (materials, water, energy) is not seen as a priority, rather the priority lies in reducing the negative environmental impact and enabling a circular life to individual elements. Reuse of waste streams is a common circular factor between these strategies. And thirdly, a building should not be seen as a static entity, rather the different layers of the building should be designed and assessed individually.

The building site is taken as a boundary condition for the assessment. This means that the flows entering and exiting a building site are studied/assessed but the origin of these flows are not assessed. Creating a system boundary enables a thorough assessment of the indicators within the set time span, resulting in a consistent (but not complete) assessment.

A set of indicators are developed within this system boundary, corresponding (mostly) to the factors of the design strategy. The indicators are as follows:
1. Energy input (Externally delivered & On-site generated)
2. Material input (On-site energy installations & Building)
3. Energy reuse
4. Energy output
5. Material output (On-site energy installations & Building)

A detailed description of the calculation methods of each indicator is given in Section 4.2. Noteworthy to mention, the material flow calculations take inspiration from Elma Durmisevic's disassembly potential (elaborated in Section 2.2.5).
The calculated quantities are flows going into and out of the building at different time periods. These flows can be in synergy or have a trade-off with each other. The determination of these flows, synergies and trade-off's creates the pathway to assess a buildings energy performance and circularity in an integrated way.
This leads to quantified data on where an improvement can be made or which synergies should be further encouraged. For instance, by increasing the energy reuse in a building, the energy input is decreased. This is advantageous for the energy performance and circularity of the building, and should therefore be encouraged.

4a. What is the data needed for the assessment of energy performance and circularity of new buildings?

The following data is needed for the calculation of each indicator in the integrated assessment method:

1. Energy input (Externally delivered & On-site generated energy):
- Quantity of delivered energy from external sources(kWh & kWh(th))
- Quantity of On-site generated energy (kWh & kWh(th))
- Source of on-site produced renewable energy
- Usable area of the building (in m^2)

2. Material input (On-site energy installations & Building):
- The composition, area and density(kg/m^2) of the used materials
- Intended use life of the element/component/material
- Technical life of the element/component/material
- Assembly sequence of the element and connection type between materials

3. Energy reuse:
- Quantitative data on types and amount of waste energy reuse (kWh/year and kWh(th)/year)
- Amount of energy stored on site (kWh/year and kWh(th)/year)

4. Energy output:
- Amount of energy exported to the grid (kWh/year and kWh(th)/year)
- Total resulting emissions (kg)

5. Material output (On-site energy installations & Building):
- Intended use period of the material
- Chemical treatments/modification done to biological materials

In this research, the above data is collected through a questionnaire focussing on self-built houses in the case study area. Both quantitative data (exact figures, measures, systems) as well as qualitative data (intentions and understandings, user satisfaction etc) are collected through this questionnaire.

ENERGY INSTALLATIONS

05

This section lay out some general details about the energy installations used in the case study assessment. This will be used in the assessments as generic data due to the unavailability of exact specification about each case. A more in depth and detailed research on the installations would provide more qualitative analysis, however within the boundary of this research, the chosen method is deemed sufficient.

The assessment cases are dependent on four types of energy inputs : Externally delivered energy from district heating, On-site energy generated from PV Panels, Solar collectors and/or biomass stove. Each of these system components are further explained with a focus on specifications that will be used in the assessments.

5.1 DISTRICT HEATING

District heating refers to a thermal grid consisting of a network of pipes connecting buildings in a neighbourhood. This system serves as a centralized plant to which a number of heating and cooling producing stations and individual buildings are connected *(Lund et al., 2014)*. Figure 27.0 depicts the evolution of the district heating system over the years.

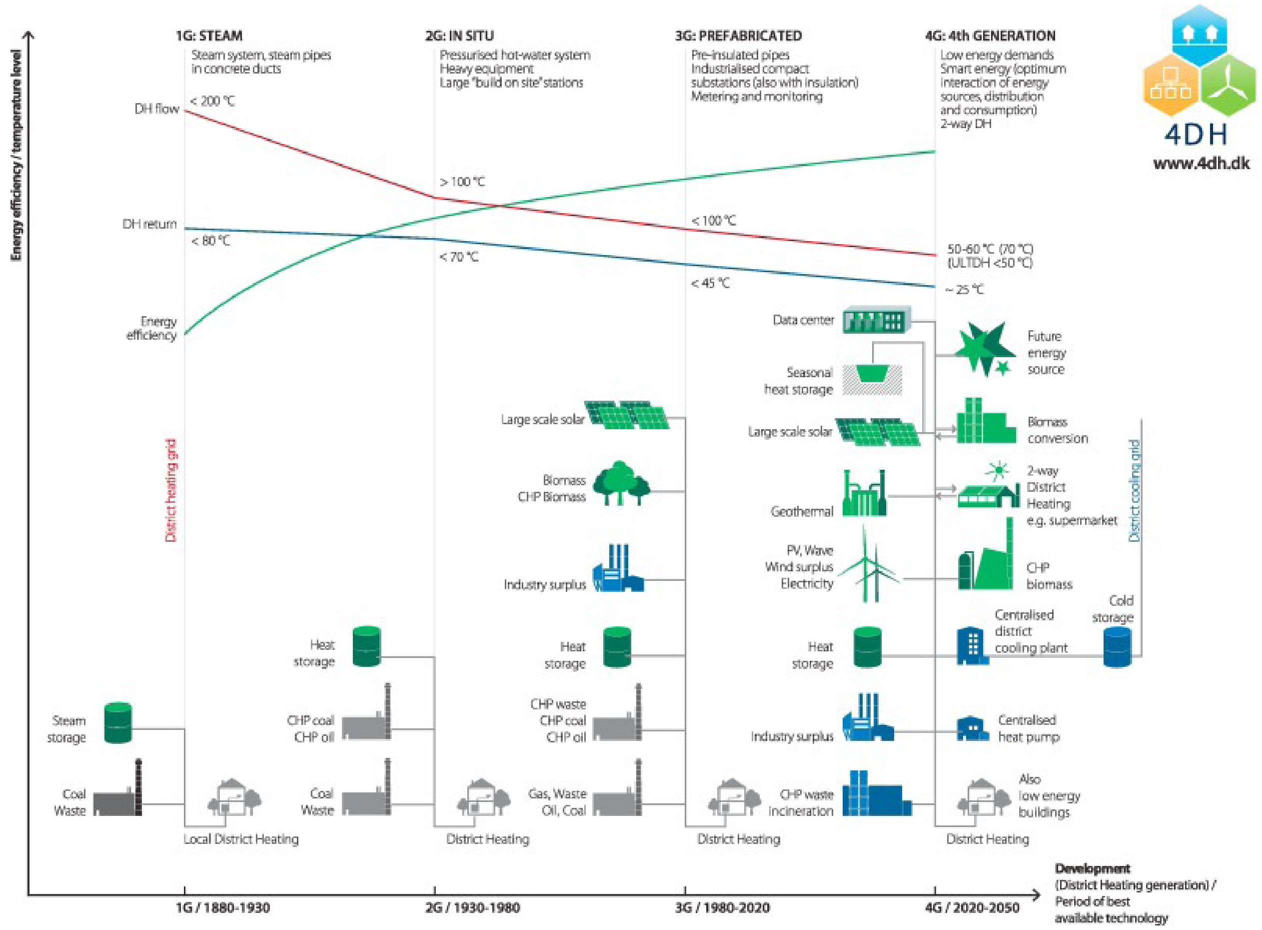


Figure 27.0 Evolution and comparison of district heating *(Lund et al., 2018)*

A district heating network consists of a heat substation, storage, distribution network and emission systems. In this research, the system boundary considered for assessment is the building site, therefore only the distribution and emission systems of the network fall within this set boundary. However, it must be noted that the circularity of the complete network must be scrutinized in order to instigate a circular change within the built environment. A circular change is not restricted to the sources of energy resources, but extends also to the material use of the whole system (which includes the substation, storage, distribution and emission channels). For example, the heat network route of such a system uses pre-insulated pipes in order to minimise the heat losses during distribution. By increasing the quantity of insulation, the heat losses are considerably reduced. However, as evident, this is an additional amount of material use which can be avoided if the network runs on low temperature supply of heat. According to studies, heat distribution becomes more efficient at lower temperatures as there is lower distribution losses due to reduced pipe expansion *(Barriers to district heating development in the Netherlands: a business model perspective, n.d.)*. Such factors must be taken into account while deciding the energy input of a building.

According to Niessink & Rosler (2015), the heat sources that can be included to generate heat and electricity in a district heating system are:

Sources	% of input (Non-renewable carrier)	% of input (Renewable carrier)
Power plants	69	
Small cogeneration (combined heat and power plant)	16	
Collective heat pumps/ ATES		1
Waste incinerator		7
Geothermal		0
Biomass / Biogas		6
Other renewables		1
Industrial waste heat		0
Total	**85**	**15**

Table 13.0 Reference data for assessment of case study *(Niessink & Rosler, 2015)*

The case study area explored in this research incorporates waste to energy as the main source for heat generation. The circularity of such a system is debatable. While on one hand the materials used for incineration are being cycled to produce a useful resource, on the other hand this results in the permanent end of the materials use life. Additionally, the circular economy aims to reduce the overall waste produced, which therefore means the quantity of waste available in the future will decrease from the present state. The result is an unreliable source for producing heat at the district level.

5.2 PV PANELS

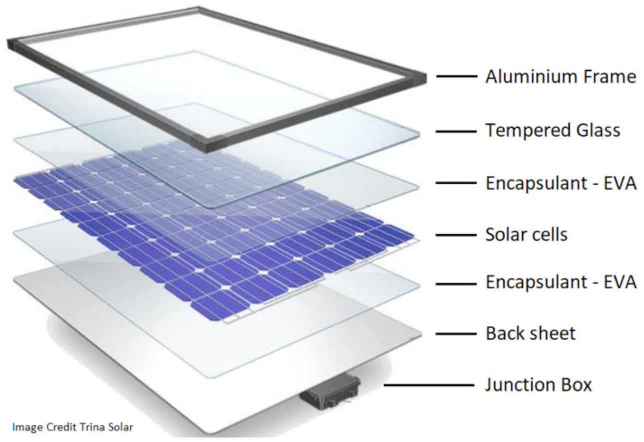
Solely dependent on solar radiation during operation, PV panels are considered as sustainable sources of energy, and is a widely used energy installation for on-site production of electricity. PV panels can be categorized into three:

1. Silicon-based (c-Si):
   a. Monocrystalline
   b. Poly or multicrytalline
   c. Ribbon
   d. a-Si (amorph/micromorph)
2. Thin-film based:
   a. Copper indium gallium (di)selenide (CIGS)
   b. Cadmium telluride (CdTe)
3. Other:
   a. Concentrating solar PV (CPV)
   b. Organic PV/dye-sensitised cells (OPV)
   c. Crystalline silicon (advanced c-Si)
   d. CIGS alternatives, heavy metals (e.g. perovskite), advanced III-V

(IRENA, 2016)

"c-Si PV is the oldest PV technology and currently dominates the market with around 95% of market share" *(IRENA, 2016)*. Therefore a standard monocrystalline PV panel is taken as reference to assess the energy and material flows in the case study.

PV modules can be broken down into 3 major components- metal, glass and silicon wafers. "c-Si technology consists of slices of solar-grade silicon, also known as wafers, made into cells and then assembled into panels and electrically connected"*(Rentoumis, Athanailidis, Koulouridakis, Katsigiannis4, & Nikolaos, 2015)*.
The typical composition of a monocrystalline panel is seen in Table 14 and Figure 28.0.



Component	Percentage of material composition
Glass cover	74,16
Aluminium frame	10,3
Encapsulant (EVA)	6,55
Solar cells	3,48
Plastic backing	3,6
Adhesive,	1,16
CU (PV panel, cabling)	0,57

Table 14.0 Constituent parts of a typical PV panel *("Solar Panel Construction — Clean Energy Reviews," n.d.)*
Figure 28.0 Material composition of a c-Si PV panel *(Rentoumis, Athanailidis, Koulouridakis, Katsigiannis4, & Nikolaos, 2015)*

"Apart from the components that are listed, a c-Si PV panel also contains very small quantities of Ag, Sn and Pb, which are not considered in this study" *(Rentoumis, Athanailidis, Koulouridakis, Katsigiannis4, & Nikolaos, 2015)*.

Other specifications:

1. Failure modes: Failure modes of a PV panel are often attributed to defects such as glass breakage, laminate or electrical defect and process losses (other defects are seen in Figure 29.0).

2. Technical life:
The technical life of a PV panel is based on the efficiency of the solar cells and is approximately 25 years.
"During the life of photovoltaic panels, a 20 per cent decrease in power capacity might occur. Between the first 10 to 12 years, the maximum decrease in efficiency is 10 per cent, and 20 per cent when reaching 25 years. However, in reality, the efficiency drops by merely 6 to 8 per cent after 25 years. The lifespan of solar panels may thus be much longer than officially stated" *("Recycling: A Solar Panel's Life after Death | GreenMatch," n.d.)*.

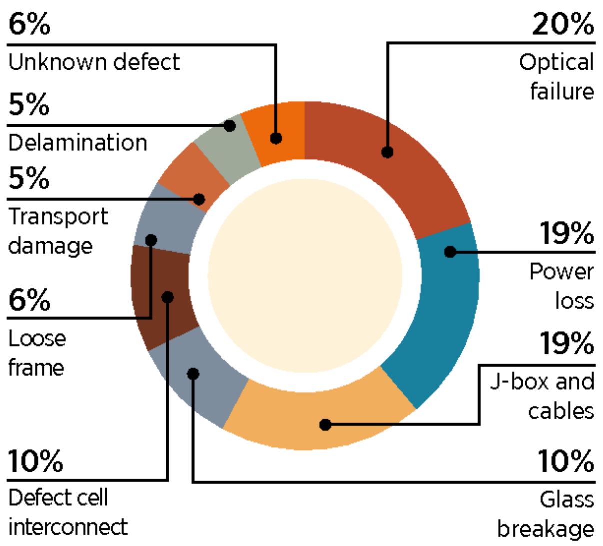


Figure 29.0 Failure modes of PV panel according to customer complaints *(IRENA, 2016)*

3. Re-usability/Recyclability:
The recycling process of silicon-based PV panels involves the following steps:
i. The product is first dismantled/disassembled to separate the aluminium and glass components." Almost all (95%) of the glass can be reused, while all external metal parts are used for re-molding cell frames" *("Recycling: A Solar Panel's Life after Death | GreenMatch," n.d.)*.
ii. To separate the binder in the panel, the other materials are treated at 500°C. The extreme heat causes the plastic encapsulant to evaporate, which is reused in the thermal processing unit as heat.
iii. The silicon cells can be then further processed. The particles are etched away using acid. The broken wafers are reused after melting for the manufacturing of new silicon modules, arriving at approximately 85% of the silicon being recycled.
("Recycling: A Solar Panel's Life after Death | GreenMatch," n.d.).

5.3 SOLAR COLLECTORS

The term "solar collector" commonly refers to a device used for solar hot water heating. The different types of solar collectors can be seen in Figure 30.0. For this study, an evacuated tube collector with heat pipe is taken as a reference.

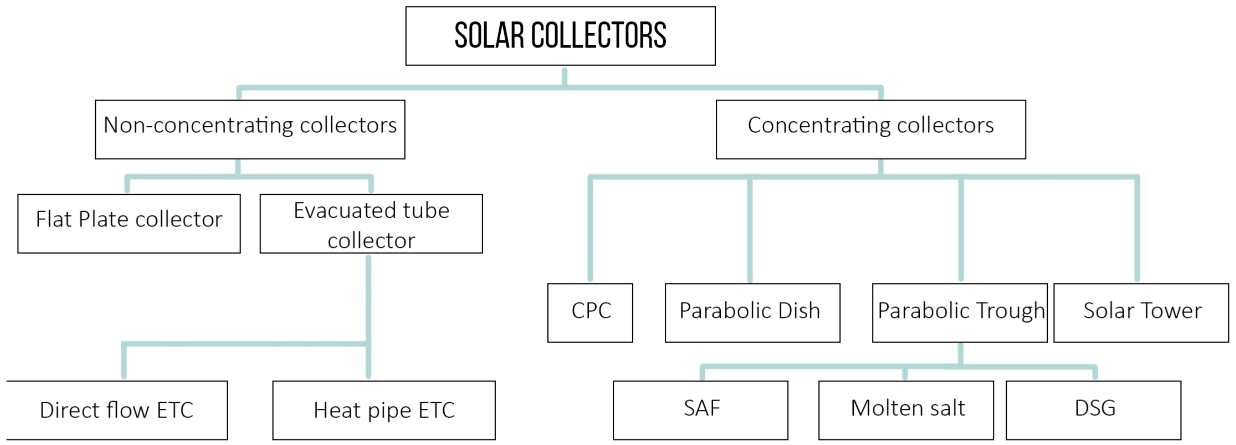


Figure 30.0 Types of solar collectors *(Report, Nagarajan, Laboratories, Barshilia, & Laboratories, 2010)*

Material properties of a typical evacuated tube collector can be seen in Figure 31.0 and Table 15.0.

Component	Material
Collector	Al/Cu/glass/Silicone/ PBT/EPDM/TE.
Glass tube	Borosilicate
Absorter coating	Aluminium nitride
Pipe	Copper

Table 15.0 Material composition of an ETC

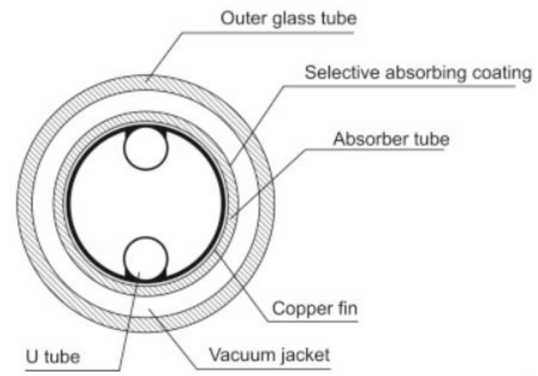


Figure 31.0 Cross-section of an ETC *(Tyagi, Kaushik, & Tyagi, 2011)*

Other specifications:

1. Failure modes:
The glass tube in this system consists of two walls of glass, between which the vacuum exists. This vacuum chamber provides heat retention in the collector, however it is also the cause of failure in the system. "If a tube were to lose it's vacuum, it is generally very easy to correct, and can be done easily by simply replacing the tube" *("Solarheat | | Solar Water Heater Stainless Steel 316L," n.d.)*

2. Technical life:
Evacuated tube collectors have life time between 15-20 years approximately. The advantage is that the tubes can be replaced individually if it is faulty or gets damaged.

5.4 BIOMASS

While biomass can be considered as a renewable energy resource, the circularity of a biomass stove is under debate even in the EU. Currently forest biomass accounts for 60% of the EU's energy source, which is equal to solar and wind energy production combined. Generally, the burning of wood in a domestic stove is regarded as a sustainable approach compared to the use of gas (for heating) as the resource used is of renewable nature and the carbon emissions produced by the stove remain a part of the carbon cycle. However, a number of other pollutants such as nitrogen dioxide, carbon monoxide and other volatile organic compounds (VOCs) are also produced as a by-product of this process, subject to the size and quality of the stove. Therefore, in this research two aspects of biomass is addressed:

(a) The calculation methodology used to determine the quantity of energy resource input for a solid biomass stove (elaborated in this section)
(b) Guidelines on the use of biomass for domestic heating (elaborated in section 7.1 Design guidelines)

Henceforth, the calculation methodology is explained:
The wood logs/pellets for the biomass stove can be categorized as either a material or energy resource, as the raw material acts as an input for on-site energy installations for the generation of energy. In order to conduct a comprehensive study, in this research it is considered as an energy resources and calculated with reference to the quantity of energy generated per m^2 per year.

Wood and pellet stoves have a high efficiency. "One tonne of willow has a calorific value of 13 Gj" *("Firewood," n.d.)* and wood pellets have a calorific value of 19 Gj per tonne *("Wood pellets: output and efficiency, heating value," n.d.)*. Based on the on-site energy generated by these stoves, the quantity of required wood is calculated as:

Type of energy resource	Type of function	On-site generated energy (kWh/year)	Carrier	Calorific value	Energy resource input (kg)	Area (m^2)	Energy resource input (kg/m^2/ year)
Wood logs	Domestic hot water	X	Renewable	= 13 GJ / tonne = $4,6 \times 10^{-5}$ kWh/kg	= X/ $4,6 \times 10^{-5}$	a	$\frac{= X/\ 4,6 \times 10^{-5}}{a}$
Wood pellets	Space heating	Y		= 19 GJ / tonne = $6,7 \times 10^{-5}$ kWh/kg	= Y/ $6,7 \times 10^{-5}$		$\frac{= Y/\ 6,7 \times 10^{-5}}{a}$

Table 16.0 Calculation of energy resources (kg /m^2/year)

06

This section answers the following sub-research questions:
5. To what extent have high energy performance and circular principles been combined in the case study buildings? Are there synergies and/or incompatibilities?

Aim of research:
The integrated assessment method is tested on three cases to quantify the flows mentioned in the framework and gain insight on the degree of circularity incorporated in these buildings. The aim of the assessments are to provide a rough but comprehensive approximation of the integration between energy and circular ambitions.
Although there may be a certain level of uncertainty due to lack of data on material and energy specifics, the assumption is made that for the overall aim of this research, the reliability of available data is sufficient for a preliminary outlook on the current state of the built environment.

6.1 INTRODUCTION

6.1.1 OVERVIEW

The assessments require a set of qualitative and quantitative data on new buildings, and so for this purpose an ambitious development in Amsterdam north is chosen. This development comprises of largely self-built houses and a collection of Collectief Particulier Opdrachtgeverschap's (CPO). The data from the self-builders and designers of this area was collected through an extensive questionnaire that covered the following topics :

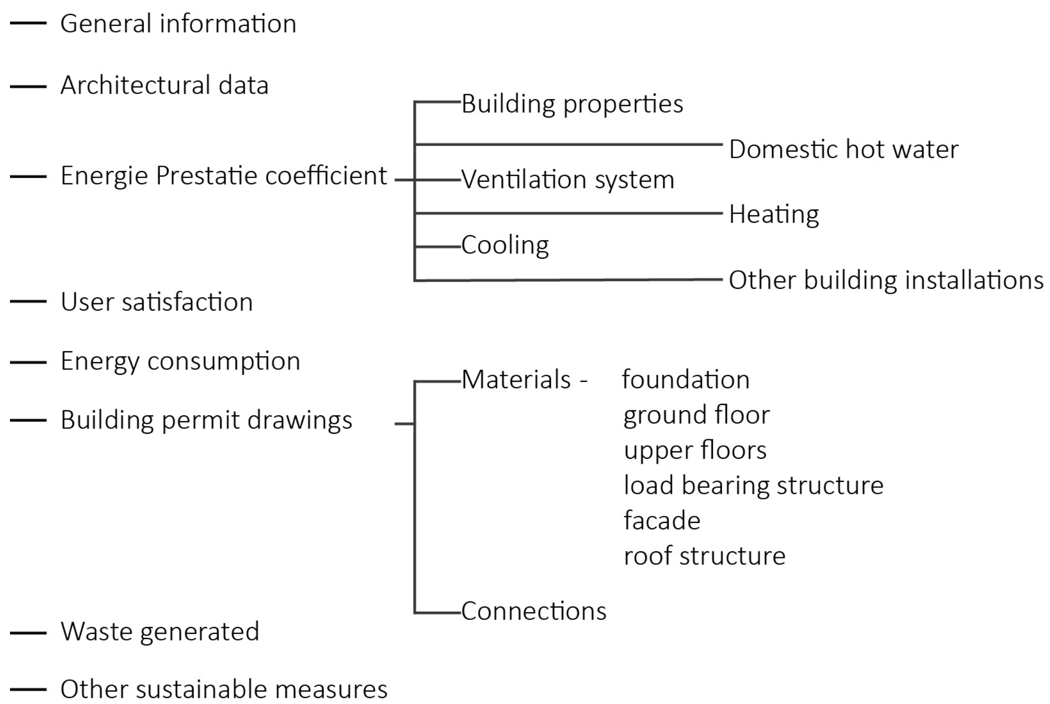


Figure 32.0 Main sections of the distributed questionnaire

6.1.1 CASE STUDY AREA - BUIKSLOTERHAM

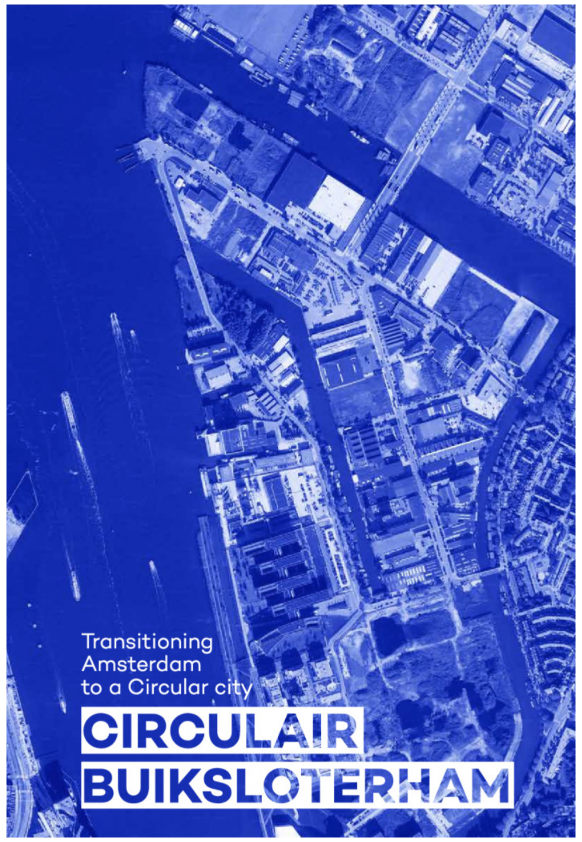
"Circular, Biobased, and Smart are core underlying paradigms for the Circular Buiksloterham Vision." *(Gladek, van Odijk, Theuws, & Herder, 2015)*

As a peripheral district with an industrial past, this development consists of many empty plots and energy and circular enthusiasts looking to transform the area into a living lab for sustainable living.
"Buiksloterham is now on the cusp of a rapid transformation" *(Gladek, van Odijk, Theuws, & Herder, 2015)*. It was estimated that by the year 2017 around 84,000 m² of new residential construction will be undertaken. To truly move towards a sustainable state, the new construction needed a new action plan with set goals and targets.

The exemplary action plan for circular Buiksloterham was developed on the following priorities for managing local resources:

1.Reducing the volume of local flows (demand-side management)
2. Finding local supply synergies (heat cascades, material cascades)
3. Supplying local flows in renewable fashion
(Gladek, van Odijk, Theuws, & Herder, 2015)

The Overarching Ambitions for Circular Buiksloterham by 2034 are as follows:
1. Energy : An energy self-sufficient neighbourhood with a fully renewable energy supply.
2. Materials and products: A zero waste neighbourhood with a near 100% circular material flow.
3. Water: Buiksloterham is rainproof and has near 100% resource recovery from waste water
4. Ecosystems and biodiversity: Buiksloterham's ecosystems are regenerated and its base of natural capital is self-renewing.
5. Socio-cultural: Buiksloterham has a diverse and inclusive culture, and a high quality, livable environment.
6. Heath and wellbeing: A healthy, safe and attractive environment with recreational activity space for all residents.
(Gladek, van Odijk, Theuws, & Herder, 2015)



(Gladek, van Odijk, Theuws, & Herder, 2015)

For this research, Buiksloterham serves as an ideal case study area as its ambitions are in line with the themes of this research. Therefore, the study of this area will provide concrete design strategies (already implemented) to integrate and efficiently combine energy and circularity in buildings, but also provide insight into the barriers in this implementation.

6.1.3 ASSUMPTIONS

As these are newly built buildings, certain assumptions are made with respect to its operational phase.
1. The use life span of assessment cases are assumed to be 75 years.
2. The energy flow calculations for the buildings are done considering an operational period of 30 years.
3. The material flow calculations for the buildings are done for the whole use lifespan, i.e., 75 years. This includes the on-site energy installations, therefore the periodic material input due to replacements are also considered for the whole lifespan.
4. As the replacement frequency of materials in the building layers (example : skin, services, stuff) are unknown, Figure 19.0 is used as a reference to determine recurrent material inflow due to replacement.

6.2 ASSESSMENT CASE 01

6.2.1 BUILDING DATA

Case 01 is a ground + four storey corner house constructed in 2016, with a usable area of 183,1 m^2. The information gathered for this case includes: the questionnaire response, EPC report and building permit drawings.

The response by the self-builder to the distributed questionnaire can be found in Appendix C (Section 12.3.1), and all subsequent gathered building information is included in Appendix C (Section 12.3.2 to 12.3.5).

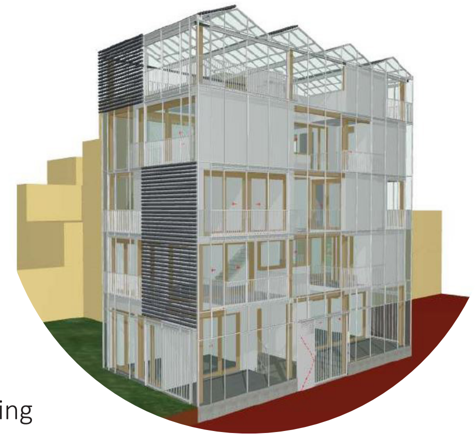


Image source: Building permit drawings

The energy performance data of this residential building (based on the provided EPC report) can be summarized as follows:

EPC	0,6 (reduced to 0,21)
External energy source(s)	District heating, Electricity grid
Space heating source(s)	Evacuated solar tubes, Biomass stove
Space heating distribution network	Underfloor heating
Domestic hot water source(s)	Evacuated solar tubes, Biomass stove
Shower heat recovery	Present
Ventilation system	Mechanical supply and discharge- central (Type Dc)
Ventilation heat recovery	Present
Active cooling system	Absent
Energy installations on site(s)	PV Panel, Evacuated solar tubes, Biomass stove
Peak power (PV panel)	120 Wp/m^2
Green roof	Absent

Table 17.0 Energy performance data of case 01. (More details in Appendix C (Section 12.3.2))

Th building has both an external supply of heat/cold/electricity and on-site generation of heat and electricity using(82 m² of evacuated solar collectors and 25,6 m² of PV panels).

The EPC calculation of this case is done in two parts. The first calculation is done using Uniec and only includes the external supply and PV panels. In order to accurately calculate the large contribution of the solar thermal energy (with seasonal storage) additional equivalence calculation is conducted. As the contribution of biomass is also included in this additional calculation, a two stage calculation in accordance with the principle of stepped requirements as laid down in the construction decree 2012 Article 5.2 paragraph 3 is done.

In the first stage, the EPC is determined by calculating the actual generation efficiency considering the energy carrier ($f_{P;\ del}$) as a fossil fuel (i.e. $F_{P;\ del;\ BM}$ = 1). The EPC of the 1st stage must meet the EPC requirement x 1.33 (for residential functions this = 1.33 x 0.60 = 0.80).

As biofuel is 100% renewable with no primary energy use within the meaning of the standard, the second stage calculation considers an energy carrier $F_{P; del; BM}$ =0. This means that in practical terms that all energy generated by biofuel is not included. These calculations are included in Appendix C (Section 12.3.2).

The building material data provided in the building permit drawings can be summarized as follows:

Ground floor	
Structural material	Reinforced concrete hollow core slab
Insulation	EPS (Rc- 5,0 m^{2}K/W)
Finishing	Cement screed
Additional layer	Underfloor heating system
Use of renewable material	Yes
Demountable connections	No
Facade	
Structural material	Wooden columns + cellulose insulation
Insulation	Fibreboard (Rc- 5,2 m^{2}K/W)
Finishing	Gypsum fibreboard
Additional layer	Greenhouse facade- laminated glass + wooden frame
Glazing	HR++ (Uvalue- 1,0 m^{2}K/W) with aluminium frame
Use of renewable material	Yes
Demountable connections	No

Table 17.1 Building materail data of case 1. (More details in Appendix C (Section 12.3.4))

By calculating the energy and material flows of this building using the detailed indicators as elaborated in Chapter 4.2, the current degree of circularity can be assessed. The calculations are explained as follows:

6.2.2 INDICATOR 1 : ENERGY INPUT

The calculation of the energy input is divided into two:
Part 1: Externally delivered energy (Thermal + Electric) / m^2 / year

According to the Uniec calculation 44,1 GJ (= 12250 kWh(th)/year) of external energy is delivered for heat/cold in the building. The total electricity use in the building is 4321 kWh/year, of which 2503 kWh/year is generated on own site (op eigen perceel opgewekte elektriciteit). Therefore externally delivered electricity = 4321-2503 = 1818 kWh/year. Table 17.0 shows the calculation in the format specified in Chapter 4.2.

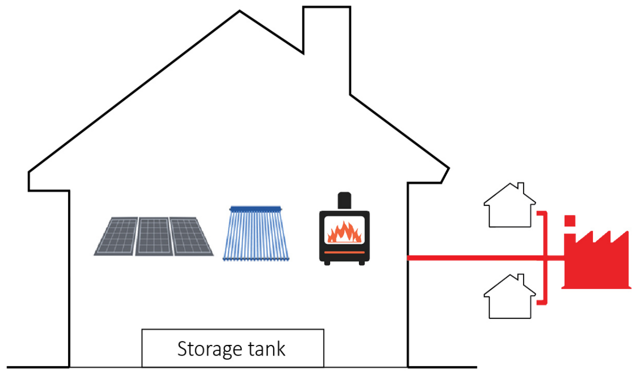


Figure 33.0 Overall scheme of the building with external and internal energy input

Type of energy	Type of function	Supply source	Primary energy use (kWh/year)	Primary energy factor	Delivered energy (kWh/ year)	Carrier	Area (m^2)	Delivered energy per m^2 (kWh/m^2/year)
Electricity	Misc.	Electricity grid	4654	2,56	1818	Renewable + Non-renewable	183,1	= 1818 / 183,1 = 10
Type of energy	Type of function	Supply source	Primary energy use (kWh(th))	Primary energy factor	Delivered energy (kWh(th))	Carrier	Area (m2)	Delivered energy per m^2(kWh(th)/m^2)
Heat	Domestic hot water	District heating	-	1,0	12250	Renewable + Non-renewable	183,1	= 12250 / 183,1 = 67
	Space heating			1,0				
Cold	Summer comfort			0,83				

Table 18.0 Calculation of delivered energy (kWh/m^2 / year)

Therefore, the Total externally delivered energy /m^2/year is

$$= \frac{\text{Externally delivered thermal energy (kWh(th)/year)}}{\text{Usable area(m}^2\text{)}} + \frac{\text{Externally delivered electric energy (kWh/year)}}{\text{Usable area(m}^2\text{)}}$$

= 67 + 10
= 77 kWh /m^2/ year
= 2310 kWh /m^2 *(for 30 years)*

Part 2: On-site generated energy (Thermal + Electric) / m^2 / year

Similarly, according to the equivalence calculation the amount of primary electrical energy needed for space heating is 6053 MJ (= 1681,4 kWh(th)/year), supplied 80% by solar collectors and remaining by biomass stove. The amount of primary electrical energy needed for domestic hot water is 1910 MJ (= 530 kWh(th)/year), supplied 90% by solar collectors and remaining by biomass stove (see Appendix C, Section 12.3.2).

Type of energy	Type of function	Supply source	Primary energy use (kWh/year)	Primary energy factor	On-site generated energy (kWh/year)	Carrier	Area (m^2)	On-site generated energy per m^2 (kWh/m^2/year)
Electricity	Misc.	PV panels	-	-	2503	Renewable	183,1	= 2503 / 183,1 = 14

Type of energy	Type of function	Supply source	Primary energy use (kWh/year)	Primary energy factor	On-site generated energy (kWh/ year)	Carrier	Area (m^2)	On-site generated energy per m^2 (kWh/m^2/year)
Heat	Domestic hot water	Solar collectors and biomass	530	1,0	530	Renewable	183,1	= 530 / 183,1 = 3
	Space heating		1681	1,0	1681			= 1681 / 183,1 = 9

Table 18.1 Calculation of on-site generated energy (kWh/m^2 / year)

Therefore, total on-site generated energy /m^2/year is

$$= \frac{\text{On-site generated thermal energy (kWh(th)/year)}}{\text{Usable area(m}^2\text{)}} + \frac{\text{On-site generated electric energy (kWh/year)}}{\text{Usable area(m}^2\text{)}}$$

= 12 + 14
= 26 kWh /m^2/ year
= 780 kWh /m^2 *(for 30 years)*

In the calculation of this indicator, the energy resources required for the on-site solid wood biomass stove should also be calculated. The wood logs/pellets for the biomass stove can be categorized as either a material or energy resource. In this research it is considered as an energy resources as the quantity of wood required is calculated per m^2 per year based on the amount of on-site generated heat. The calculation is as follows:

Type of energy resource	Type of function	On-site generated energy (kWh/year)	Carrier	Calorific value	Energy resource input (kg)	Area (m^2)	Energy resource input (kg/m^2/year)
Wood	Domestic hot water	= 10% of 530 = 53	Renewable	= 13 GJ / tonne = 4,6 x 10^{-5} kWh/kg	= 53 / 4,6 x 10^{-5} = 15	183,1	= 15 / 183,1 = 0,08
	Space heating	= 20% of 1681 = 336,2			= 336,2 / 4,6 x 10^{-5} = 93		= 93 / 183,1 = 0,5

Table 18.2 Calculation of energy resources (kg /m^2 / year)

Therefore the total input of energy resources /m^2/ year = 0,6 kg/m^2/year
= 18 kg/m^2 *(for 30 years)*

6.2.3 INDICATOR 2 : MATERIAL INPUT (ON-SITE ENERGY INSTALLATIONS & BUILDING)

1. On-site energy installations:

According to the EPC report, this building has three on-site energy installations: 25,6 m^2 of PV panels, 82 m^2 of evacuated solar tubes and a biomass stove. Using the general material specifications (See section 5.1 & 5.2), the material input of these installations can be calculated as:

Step 1: Determining the environmental load (= MPG score) of the system.

The calculation method used is MRPI-MPG software. The score for 25,6 m^2 of PV panels + 82 m^2 of vacuum tube is calculated as 0,49. **See appendix C (Section 12.3.5) for calculation reference*

Step 2: Determining the initial material input of the installations :

Initial material input(kg) = Material input per m^2 (kg/m^2) x Installation area (m^2)

On-site installation	Material description	Material input per m^2 (kg/m^2)	Area (m^2)	Technical life (years)	Initial material input (kg)	MPG Score
PV Panels	(i) Cover- Glass; (ii) Encapsulation- Plastic, (iii) Frame- Aluminium; (iv)Solar cells- Silicon; (v)Connector ribbons- Metal	11,4	25,6	25	= 11,4 x 25,6 = 291 (for 25 years)	0,49
Vacuum tubes	Evacuated solar tube collector consists of four components- (i) Collector material: Al/Cu/glass/ Silicone/ PBT/EPDM/TE. (ii)Glass tube material: Borosilicate glass. (iii)Absorber coating: aluminium nitride. (iv)Pipe material: copper	19,0	82,0	15 - 20	= 19,0 x 82,0 = 1558 (for 15-20 years)	

Table 19.0 Calculation of Initial material input of on-site energy installations

Step 3: Determining the additional material input of the installations :

Additional material input(kg) = Initial material input (kg) x Replacement frequency

Energy supply source	Initial material input (kg)	Replacement frequency	Elaboration	Additional material input (kg)
PV Panels	291	= Building life / Technical life of the installation = 75/ 25 = 3	With a technical life = 25 years, PV panels have to be replaced 3 times during use life.	= 291 x 2 = 582
Vacuum tubes	1558	= Building life / Technical life of the installation = 75/ 20 = 3,5	Evacuated tube collectors have life time between 15-20 years approximately. Therefore the tubes have to be replaced 3,5 times during use life of the building.	= 1558 x 2,5 = 3895

Table 19.1 Calculation of additional material input for on-site energy installations

In this assessment, additional material use in case of repair/ wear and tear is not studied. Additional material use is attributed to the material input for complete replacement of the system, that is required at the end of technical life of the system.

Summing up the analysis, the total material input by on-site energy installations = 291 + 1558 + 582 + 3895
= 6326 kg

Therefore, the Total material input /m^2 = $\frac{\text{Total material input (kg)}}{\text{Usable area of the building(m}^2\text{)}} = \frac{6326}{183,1}$ = 35 kg / m^2

To determine the circularity of this material input, the theoretical re-usability of the output must be determined. This is done using Indicator 5.

2. Building

Similar to the calculation on on-site energy installations, the total material input for the building can be calculated. In this research, the scope is limited to the ground floor and skin of the building. The quantities calculated are:

Initial material input (kg) = S x t x A
Additional material input (kg) = Initial material input (kg) x R

where,
S = Density of materials in kg/m^3
t = Thickness of the material in m
A = Area of the material in m^2
R = Replacement frequency

The building permit drawings and EPC report acts as the source of information for extracting material specifications of the building. As the exact replacement frequency of the material is not known, Figure 19.0 (Section 4.1.1) is taken as a reference. According to this figure, the structure of the building is not replaced, while the skin is replaced 2 times during the life of the building.

The material input for the ground floor is calculated as follows:

Step 1 : The ground floor comprises of three materials of varying thickness's (Figure 34.0). The density (kg/m^3) of each material is determined through literature study.

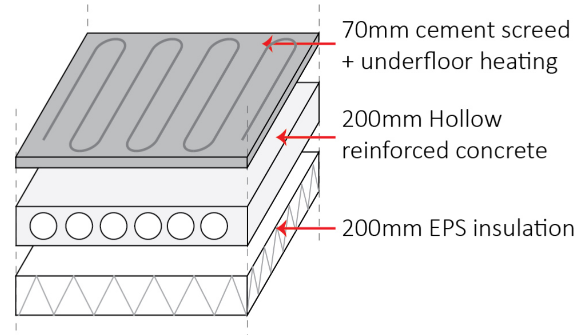


Figure 34.0 Material specifications

Step 2: The area of the structure is taken from the BVO summary in the permit drawings. According to figure 34.1, the area of the ground floor is 23,94 m^2 + 24,05 m^2 = 48 m^2

Step 3: The are of the insulation and finish is taken from the GBO summary in the permit drawings. The GBO gives the area of floor minus the wall thickness. According to figure 33.2, this area is 19,81 m^2 + 19,43 m^2 = 39 m^2

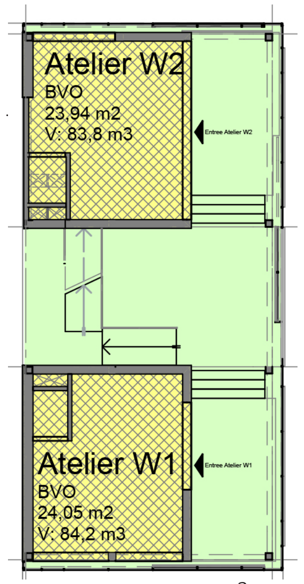


Figure 34.1 BVO (m^2)

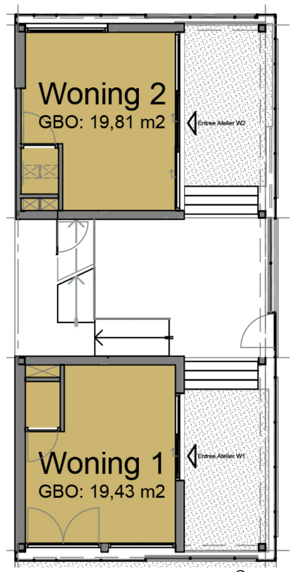


Figure 34.2 GBO (m^2)

Step 4: The initial material input is thus calculated as density (kg/m^3) x thickness (m) x area (m^2).

Component layer	Sub-layer	Material Type	Density (kg/m^3)	Thickness (m)	Area (m^2)	Initial material input (kg)	Replacement frequency (no. of times)	Additional material input (kg)
Ground floor	Structure	Hollow reinforced concrete	1355	0,2	48	= 1355 x 0,2 x 48 = 13008	0	0
	Insulation	EPS	11	0,2	39	= 11 x 0,2 x 39 = 86	0	0

Ground floor	Finish	Cement screed (with floor heating)	2000	0,07	39	= 2000 x 0,07 x 39 = 5460	0	0

Table 19.2 Calculation of initial and additional material use of the building

Similar to the calculation of the ground floor, the building information about the facade for steps 1,2 and 3 are extracted from the permit drawings. Finally, the initial and additional material input (kg) for the facade is calculated as:

Component layer	Sub-layer	Material Type	Density (kg/m^3)	Thickness (m)	Area (m^2)	Initial material input (kg)	Replace-ment frequency	Additional material input (kg)
Facade	Structure	Wooden frame	470	0,18	269	= 470 x 0,18 x 269 = 22741	0	0
	Insulation	Cellulose insulation+ fibreboard	50 + 180	0,18 + 0,04		= (50 x 0,18 x 269) + (180 x 0,04 x 269) = 4355	1	4355
	Finish	Gypsum fiberboard	1150	0,015		= 1150 x 0,015 x 269 = 4637	1	4637
	Glazing	HR++ glazing	2550	0,008	132	= 2550 x 0,008 x 132 = 2698	1	2698
	Additional layer	Greenhouse - Al Frame	121	0,05	151	= 121 x 0,015 x 151 = 911	1	911
		Greenhouse - laminated glass	2550	0,004	255	= 2550 x 0,004 x 255 = 2550	1	2550

Table 19.3 Calculation of initial and additional material use of the building

Summing up, the total material input by the building = 13008 + 86 + 22741 +4355 + 4637 +2698 + 911 +2550
= 71597 kg

Therefore, the Total material input /m^2 = $\frac{\text{Total material input (kg)}}{\text{Usable area of the building(m}^2\text{)}}$ = 391 kg / m^2

From this assessment, it can already by seen that the bulk of the material input can be attributed to the structure of the building. Intelligent dimensioning of the material has been considered. The structure of the floor is made up of hollow reinforced concrete, which is a prefabricated material and provides material savings due to precision in production.

6.2.4 INDICATOR 3 : ENERGY REUSE

According to the EPC report, the waste heat generated by the central ventilation unit and shower is recovered and reused in the building.

The quantity of shower heat recovered and reused is calculated in the following manner: Assuming 50% of the electrical energy delivered for domestic hot water use is used for the shower, and estimating a return of 40% from the DWTW shower heat recovery, reused heat is = 0,5 x 0,4 x 531 = 106 kWh(th).

The quantity of central ventilation waste heat reused is calculated using Uniec in the following manner:
1. The calculation is replicated, and the same ventilation system is maintained.
2. System variant of the ventilation system is changed to D1 standard (no heat recovery)
3. Difference in ventilation energy use between original and modified calculation is noted.

The result is a difference of 9627- 4870 MJ = 4757 MJ
= 1321 kWh(th) / year

In addition to the waste energy reused in the building, all thermal energy generated on site is stored in a buffer tank in the basement of the building, which is equal to 2210 kWh(th) / year.
Therefore, the total energy reused = 106 + 1321 + 2210 = 3637 kWh(th) / year

The total energy reused /m^2 = $\frac{\text{Total energy reused (kWh(th))}}{\text{Usable area of the building(m}^2\text{)}}$ = 20 kWh (th)/m^2/ year

= 600 kWh (th)/m^2 ***(for 30 years)***

6.2.5 INDICATOR 4 : ENERGY OUTPUT

According to the EPC report, the surplus energy generated is stored in the building and not exported to the grid. The following is concluded from an analysis of the Uniec calculation:

1. Energy exported per m^2 = 0,0 kWh/m^2
3. Co2 emissions per m^2 = 31 kg/m^2/ year
= 930 kg/m^2/ year ***(for 30 years)***

The presence of Co² emissions can be possibly attributed to the connection to district heating. These emissions although beyond the system boundary, must be considered as a factor in the design phase of the building, hence the study of the emissions is important to the assessment.

6.2.6 INDICATOR 5 : MATERIAL OUTPUT

Similar to the calculation of Indicator 3, the material output from a building is divided into two:

1. On-site energy installations:

Using the literature review of energy installations elaborated in Section 5.2 & 5.3, the circular (reused/recycled) and non-circular (waste) output of on-site installations can be determined. This is further elaborated in Table 20.0.

Energy supply source	Connection type	Theoretical reusability	End of life possibility	Reused / Recycled material (kg)	Waste material(kg)
PV Panel	Connection between EVA and Solar cells : Filled. All other connections: Indirect	Approximately 85% of the total panel mass can be reused/ recycled(up).	The metal and glass can be recycled using current recycling infrastructure, while silicon cells that are intact after pyrolysis and etching can be processed into new cells using standard solar cell production technique.	= 0,85 x 872 = 741	= 872 - 741 = 131
Solar collectors	Direct connections between two pre-made components OR Filled connection	Not directly reusable/ not directly recyclable	Unknown		

Table 20.0 Categorization of material output from on-site energy installations

Summarizing the assessment of on-site energy installations with reference to the usable area of the building for a building life span of 75 years:
Theoretically reusable/ recyclable material/ m^2 = 741 / 183,1 = 4,0 kg/m^2
Waste material / m^2 = 131 / 183,1 = 0,7 kg/m^2
Unknown end of life / m^2 = (1558+3895) / 183,1 = 30 kg/m^2

2. Building
Similarly, the material output of the building can be categorized into reusable/recyclable resource or waste. The assessment of the theoretical resuablity of the materials in each building layer is based on the information provided in the questionnaire and building permit drawings. From the questionnaire, it is known whether reversible or irreversible connections have been used; and from the building permit drawings the use of prefabricated materials can be deduced.

Connection type	Theoretical reusability	Reused / Recycled material (kg)	Waste material(kg)
Ground floor: Structure- Insulation	Reversible connections (bolts, screws) have not been used. Therefore, the elements are assumed to be completely integrated. Theoretical reusability of insulation = not directly reusable	= Mass of structure = 13008	= Mass of insulation = 86
Ground floor: Structure- Finish	Hollow core slab is a prefab element. The cement screed + underfloor heating are not irreversibly attached to the structure. Theoretical reusability = Reusable/Recyclable		= Mass of finish = 5460
Facade: Structure- Insulation	The recylability of wood depends on the maintenance and quality of the product. This is unknown. In terms of insulation: The structure consists of cellulose insulation, and an additional layer of fibreboard is used. Due to non-demountable connections--Theoretical reusability of insulation = not directly reusable		
Facade: Structure- Finish	Gypsum fiber board finish is made up of cellulose fibres of recycled paper. The fixing detail is usually with screws that makes the material theoretically recyclable. According to data however, demountable connections have not been used in this case, therefore elements are assumed to be completely integrated.		Mass of insulation + finish = 17984
Facade: Frame-Glazing	Insulated glass units are recyclable to float line, however it requires removal of the spacer bars and edge seals; and consists of limitations in processing. The glass unit itself has a higher life expectancy but must be frequently replaced due to the edge sealants that have a shorter life span	Mass of frame + glazing =5395	
Greenhouse: Frame-Glass	There is complete separation between the aluminium frame and laminated glass. However additional analysis of the reusability of glass needs to be considered in this analysis. As laminated glass has limited recyclability. The current method for delaminating reduces quality. This means glass is downcycled and used in mineral wool/ insulation (Arup, n.d.).	Mass of frame + glass = 6923	

Table 20.1 Categorization of material output from building materials

Summarizing the assessment of building materials with reference to the usable area of the building for a building life span of 75 years:

Theoretically reusable/ recyclable material / m^2 = (13008 + 5395 + 6923)/183,1 = 137 kg/m^2
Waste material / m^2 = (86 + 5460 + 17984)/183,1 = 128 kg/m^2
Unknown end of life / m^2= 124 kg/m^2

6.2.7 CONCLUSION

Using the assessment framework, the current degree of circularity in terms of energy use and building materials can be extracted.

In terms of the building design,
In total, for the ground floor and facade 391 kg/m^2 of materials is required, out of which 39 kg/m^2 is reused or recycled (up) after the technical life of the component has ended. This only represents 10% of the total material input. 98 kg/m^2 of the material going into the building, is downcycled at the end of life, representing nearly 25% of the input.
Therefore only 35% of the material input of the building is reused or recycled in some form, however technically only 10% of this is circular, as downcycling is not a circular process because it does not lead to the continuous cycling of resources.

Furthermore, it is seen that 128 kg/m^2 of the materials end up as waste, which can be either processed for incineration to produce energy or could end up in a landfill. Waste represents 32% of the material input here.

Due to insufficient data on the exact specifics of the remaining materials used, it is attributed to being unknown in this study and not included in determining the degree of circularity.
It can be understood from this that more material ends up as waste in this building at the end of life. According to the analysis, this is a result of insufficient demountable connections between materials, use of non-renewable materials and irreversible treatments applied to renewable materials.
For example, in this building, a large quantity of laminated glass has been used for a greenhouse facade. While there is complete separation of materials (frame to glass), laminated glass itself has limited recyclability due to the lamination/treatment. The current method for de-laminating reduced quality, which means the glass is downcycled and used in mineral wool insulation *(Arup, n.d.)*.

In terms of energy use (input + reuse + output),
52% of the energy input is from district heating and electricity grid. From Section 5.1, it is known that the resources that go into this production comes from both renewable and non-renewable sources. This is therefore a potential area of improvement.
While the building does not produces surplus energy to be returned to the grid, it does store all thermal energy to be used as demand arises. An area of improvement is in the reuse or mitigation of Co^2 emissions of the building.
The above analysis and conclusion is represented schematically in Figure 35.0.

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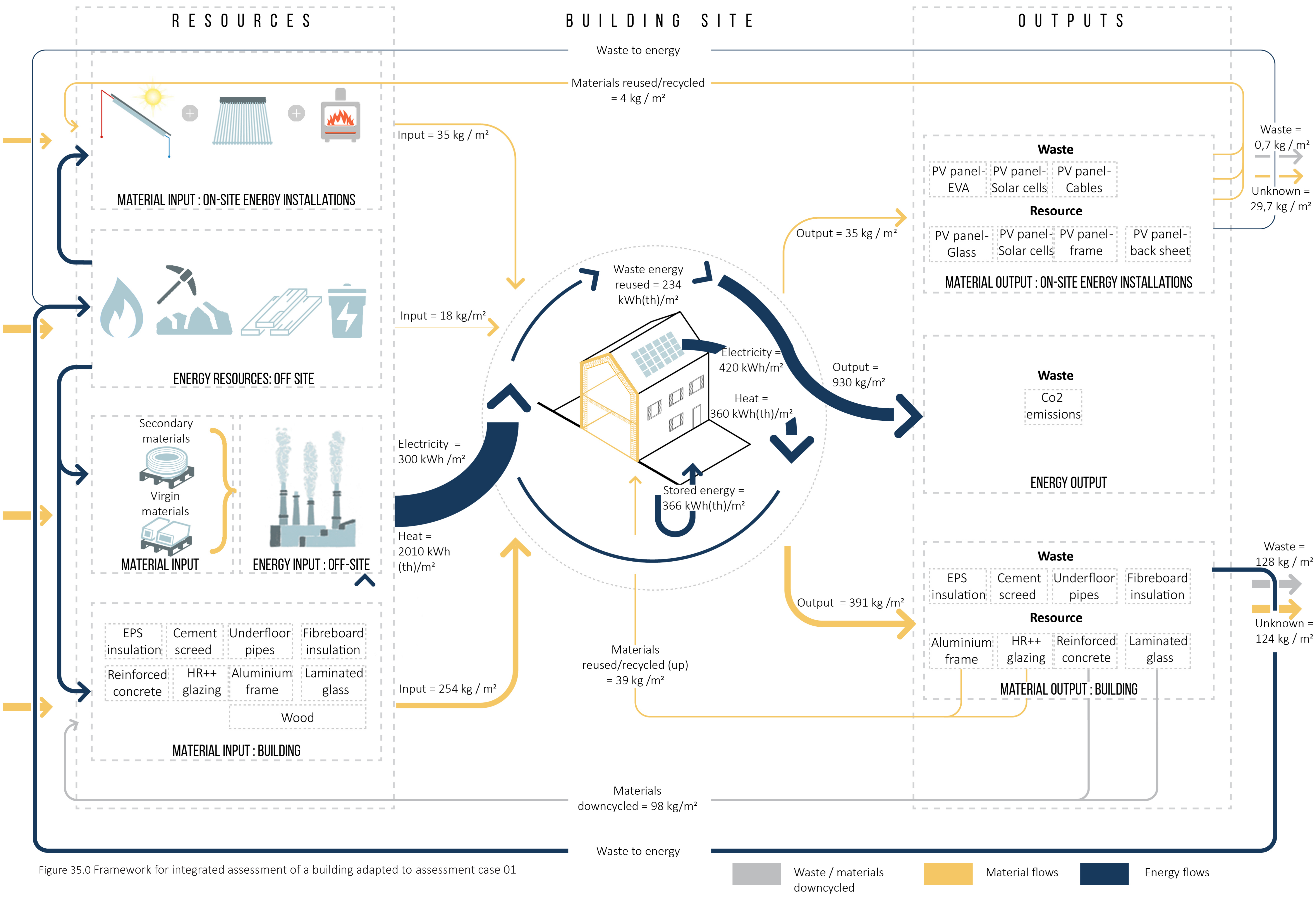

Figure 35.0 Framework for integrated assessment of a building adapted to assessment case 01

6.3 ASSESSMENT CASE 02

6.3.1 BUILDING DATA

Image source: Zelfbouw

Case 02 is a ground + two storey corner house constructed in 2016, with a usable area of 64,48 m^2. Similar to Case 01, the building information of this building has been gathered using a questionnaire. The response by the resident to the questionnaire is included in Appendix D (Section 12.4.1), and all subsequently gathered building information is included in Appendix D (Section 12.4.2 to 12.4.5).

The energy performance data of this residential building (based on the provided EPC report) can be summarized as follows:

EPC	-0,08
External energy source(s)	Electricity grid
Space heating source(s)	Pellet boiler
Space heating distribution network	Underfloor heating
Domestic hot water source(s)	1 Small wood stove, Solar collector, Heat pump
Shower heat recovery	Present
Ventilation system	Natural supply and Mechanical discharge (Type C)
Ventilation heat recovery	Absent
Active cooling system	Absent
Energy installations on site(s)	PV Panel
Peak power (PV panel)	135 Wp/m^2
Green roof	Present

Table 21.0 Energy performance data of case 02. (More details in Appendix D (Section 12.4.2))

Unlike Case 01, Case 02 relies mainly on on-site generated energy to meet building system needs. The building uses 4,5 m^2 of solar collectors and 9,3 m^2 of PV panels on site.

The EPC calculation of this case is also done in two parts, owing to the use of biomass in the building and is calculated in accordance with the principle of stepped requirements as laid down in the construction decree 2012 Article 5.2 paragraph 3.

In the first stage, the EPC is determined by calculating the actual generation efficiency considering the energy carrier (fP; del) as a fossil fuel (i.e. FP; del; BM = 1). The EPC of the 1st stage must meet the EPC requirement x 1.33 (for residential functions this = 1.33 x 0.60 = 0.80). As biofuel is 100% renewable with no primary energy use within the meaning of the standard, the second stage calculation considers energy carrier FP; del; BM =0. This means that in practical terms that all energy generated by biofuel is not included. The Uniec calculations of both stages can be found in Appendix D Section 12.4.2

The building material data provided in the building permit drawings can be summarized as follows:

Ground floor	
Structural material	Reinforced concrete hollow core slab
Insulation	EPC (Rc- 6,5 m^2K/W)
Finishing	Cement screed
Additional layer	Underfloor heating system
Use of renewable material	Yes
Demountable connections	Yes
Facade	
Structural material	Sand-lime brick
Insulation	Sandwich panel (Rc- 5,0 m^2K/W)
Finishing	Steel profile plate + Stucco
Additional layer	-
Glazing	HR++ (Uvalue- 1,0 m^2K/W) with wooden frame
Use of renewable material	Yes
Demountable connections	Yes

Table 21.1 Building material data of case 2. (More details in Appendix D (Section 12.4.4))

Using the detailed indicators as elaborated in Section 4.2 in a manner similar to the assessment of Case 01, the energy and material flows of this building can be quantified. The calculations are explained as follows:

6.3.2 INDICATOR 1 : ENERGY INPUT

The calculation of the energy input is divided into two:
Part 1: Externally delivered energy (Thermal + Electric) / m^2 / year

According to the Uniec calculation, the total electricity use in the building is 1402 kWh/year, of which 1130 kWh/year is generated on own site (op eigen perceel opgewekte elektriciteit). Therefore externally delivered electricity = 1402-1130 = 272 kWh/year. Table 21.0 shows the calculation in the format specified in Section 4.2.1.

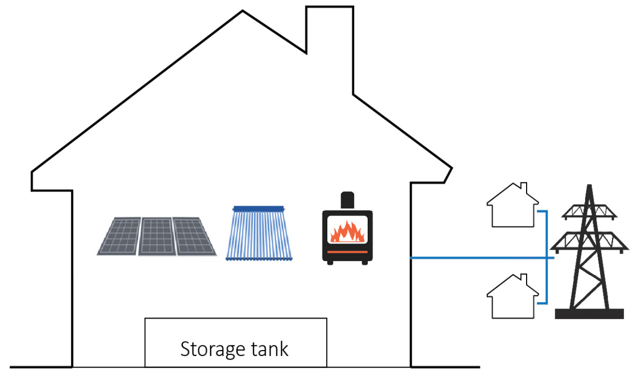

Figure 36.0 Overall scheme of the building with external and internal energy input

Type of energy	Type of function	Supply source	Primary energy use (kWh/year)	Primary energy factor	Delivered energy (kWh/ year)	Carrier	Area (m^2)	Delivered energy per m^2 (kWh/m^2/year)
Electricity	Misc.	Electricity grid	696,3	2,56	272	Renewable + Non-renewable	64,84	= 272 / 64,84 = 4

Table 22.0 Calculation of delivered energy (kWh/m^2 / year)

The Total externally delivered energy /m^2/year is

$$= \frac{\text{Externally delivered thermal energy (kWh(th)/year)}}{\text{Usable area (m}^2\text{)}} + \frac{\text{Externally delivered electric energy (kWh/year)}}{\text{Usable area (m}^2\text{)}}$$

= 4 kWh /m^2 / year

= 120 kWh /m^2 / year *(for 30 years)*

Part 2: On-site generated energy (Thermal + Electric) / m^2 / year

Similarly, according to the equivalence calculation the amount of primary electrical energy needed for space heating is 12345 MJ (= 3429,2 kWh(th)/year), provided by a pellet boiler, and the amount of primary electrical energy needed for domestic hot water is 3928 MJ (= 1091,1 kWh(th)/year), supplied by the wood stove, and when required by the solar collector and heat pump. (see Appendix D, Section 12.4.2).

Type of energy	Type of function	Supply source	Primary energy use (kWh/year)	Primary energy factor	On-site generated energy (kWh/year)	Carrier	Area (m^2)	On-site generated energy per m^2 (kWh/m^2/year)
Electricity	Misc.	PV panels	-	-	1130	Renewable	64,84	= 1130 / 64,84 = 17
Heat	Domestic hot water	Wood stove, solar collector, heat pump	1091,1	Na	1091			= 1091 / 64,84 = 17
	Space heating	Pellet boiler	3429,2		3429			= 3429 / 64,84 = 53

Table 22.1 Calculation of on-site generated energy (kWh/m^2 / year)

The Total on-site generated energy /m^2/year is

$$= \frac{\text{On-site generated thermal energy (kWh(th)/year)}}{\text{Usable area(m}^2\text{)}} + \frac{\text{On-site generated electric energy (kWh/year)}}{\text{Usable area(m}^2\text{)}}$$

= 70 + 17

= 87 kWh /m^2 / year

= 2610 kWh /m^2 *(for 30 years)*

In the calculation of this indicator, the energy resources required for the biomass should also be calculated.

According to the information collected via the questionnaire, 2500 kg of pellets are used per year to meet the space heating and domestic hot water demand. With reference to the usable area of the building, this translates to 39 kg/m^2/year of pellets.

6.2.3 INDICATOR 2 : MATERIAL INPUT (ON-SITE ENERGY INSTALLATIONS & BUILDING)

According to the EPC report, this building has three types of on-site energy installations: 9,3 m^2 of PV panels, 4,5 m^2 of evacuated solar tubes and two biomass stoves. Using the general material specifications (See Section 5.1, 5.2 & 5.3), the material input of these installations can be calculated as:

Step 1: Determining the environmental load (= MPG score) of the system.
Using MRPI-MPG software, the MPG score is calculated as 0,32.
**See appendix D for calculation reference*

Step 2: Determining the initial material input of the installations :

Initial material input(kg) = Material input per m^2 (kg/m^2) x Installation area (m^2)
Similar to Case 01 (see Section 6.2.3, Table 19.0), the initial material input is calculated as 190,7 kg.

Step 3: Determining the additional material input of the installations :

Additional material input(kg) = Initial material input (kg) x Replacement frequency
Again, following the same method of calculation as Case 01, the additional material input is calculated as 424,2 kg.

Therefore, the Total material input /m^2 = $\frac{\text{Total material input (kg)}}{\text{Usable area of the building(m}^2\text{)}} = \frac{191 + 424}{64,84} =$ 9 kg / m^2

To determine the circularity of this material input, the theoretical re-usability of the output must be determined using indicator 5. Similarly, the total material input for the building can be calculated using the formula:

Initial material input (kg) = Density of the material (kg/m^3) x thickness (m) x Area of the material (m^2)

Additional material input (kg) = Initial material input (kg) x R

The building permit drawings and EPC report acts as the source of information for extracting material specifications of the building. As the exact replacement frequency of the material is not known, Figure 19.0 (Section 4.1.1) is taken as a reference. The calculation is therefore as follows:

Component layer	Sub-layer	Material Type	Density (kg/m^3)	Thickness (m)	Area (m^2)	Initial material input (kg)	Replace-ment frequency	Additional material input (kg)
Ground floor	Structure	Hollow reinforced concrete	1355	0,26	64,84	= 1355 x 0,26 x 64,8 = 17572	0	0
	Insulation	Unknown	-	0,02		0,0	0	0
	Finish	Cement screed (with floor heating)	2000	0,06		= 2000 x 0,06 x 64,84 = 7781	0	0
Facade	Structure	Sand lime brick	1628	0,15	33,16	= 1628 x 0,15 x 33 = 8098	0	0
	Insulation	Sandwich panel	130	0,12		= 130 x 0,12 x 33 = 515	1	515
	Finish	Steel profile plate	10,4	0,75		= 10 x 0,75 x 33 = 260	1	260
		Stucco	2200	0,01		= 2200 x 0,01 x 33 = 730		730
	Glazing	HR++ glazing	2550	0,008	5,79	= 2550 x 0,008 x 5,79 = 118	1	118
		Wooden frame	Unknown					

Table 23.0 Calculation of initial and additional material use of the building

Summarizing,
Total initial material input = 35072 kg
And, total additional material input = 1622 kg

Therefore, the total material input by the building = 35072 + 1622
= 36694 kg

And, Total material input /m^2 = $\frac{\text{Total material input (kg)}}{\text{Usable area of the building(m}^2\text{)}}$ = 566 kg / m^2

6.2.4 INDICATOR 3 : ENERGY REUSE

According to the EPC report, the waste heat generated by the shower and ventilation is recovered and reused in the building.

The quantity of shower heat recovered and reused is calculated in the following manner: Assuming 50% of the electrical energy delivered for domestic hot water use is used for the shower, and estimating a return of 40% from the DWTW shower heat recovery, reused heat is = 355 kWh(th) / year.

The quantity of waste heat recovered from the ventilation system is calculated using Uniec in the following manner:
1. The calculation is replicated, and the same ventilation system is maintained.
2. System variant of the ventilation system is changed to D1 standard (no heat recovery).
3. Difference in ventilation energy use between original and modified calculation is noted.

The result is a difference of 3173 - 823 MJ = 2350 MJ
= 653 kWh(th) / year.
In addition to the waste energy reused in the building, all thermal energy generated on site is stored in a buffer tank in the basement of the building, which is equal to 4520,3 kWh(th) / year.
Therefore, the total energy reused = 355 + 4520 + 653 = 5528 kWh(th) / year

The total energy reused /m^2 = $\frac{\text{Total energy reused (kWh(th))}}{\text{Usable area of the building(m}^2\text{)}}$ = 85 kWh(th) / m^2/year
= 2550 kWh(th)/m^2 *(for 30 years)*

6.2.5 INDICATOR 4 : ENERGY OUTPUT

In this building, the energy output in the form of carbon emissions are collected in a fine dust filter. According to the Uniec calculation these emissions = - 235kg or- 111 kg/m^2 for 30 years.

6.2.6 INDICATOR 5 : MATERIAL OUTPUT

The material output from a building is divided into two:

1. On-site energy installations:

Using the literature review of energy installations, elaborated in Section 5.2 & 5.3, the circular (reused/recycled) and non-circular (waste) output of on-site installations can be determined in the same manner as Case 01 (Table 19.0).

Summarizing the assessment of on-site energy installations with reference to the usable area of the building:

Theoretically reusable/ recyclable material / m^2 = 4 kg/m^2
Waste material / m^2 = 0,7 kg/m^2
Unknown end of life / m^2= 5 kg/m^2

2. Building:

Similarly, the material output of the building can be categorized into reusable/recyclable resource or waste (Table 24.0) . The assessment of theoretical resuablity of the materials in each building layer is based on the information provided in the questionnaire and building permit drawings.

Connection type	Theoretical reusability	Reused / Recycled material (kg)	Waste material(kg)
Ground floor: Structure - Insulation	The recyclability of the insulation depends on the type of material. The connection type is also unknown.		
Ground floor: Structure - Finish	Hollow core slab is a prefab element. The cement screed + underfloor heating is not irreversibly attached to the structure. Theoretical re-usability = Reusable/Recyclable	= Mass of the structure =17572	= Mass of the finish = 7781
Facade: Structure - Insulation	Exact data on the connection type is unknown, however due to the nature of the products, the type can be deduced. Both materials are pre-made components and assembled on site to facilitate ease and speed of construction. Therefore the connection type is assumed to be: Indirect with additional fixing. However, here additional study is needed to determine re-usability. Although sand-lime bricks are renewable, bricks are generally fixed with strong mortar that usually only breaks after the brick itself, therefore most often bricks are cut up in a plant and is down-cycled.	Mass of the structure = 8098	
Facade: Insulation - Finish	The steel profile and sandwich panel is separated by a ventilated cavity. The layers are connected by screwed connections. Therefore as connection type = Indirect connection via independent third component, Theoretical re-usability (of steel profile plate) = Reusable / Recyclable	Recyclability of the sandwich panel also depends on the insulation material, which is not known.	
		= Mass of the finish = 520	
Facade: Structure- Finish	The finishing on the external side of the façade is stucco. The plastering wears out during the use life of the building and is frequently reapplied. After use life, it is discarded as waste.		Mass of the finish = 1460
Facade: Frame - Glazing	Insulated glass units are recyclable to float line, however it requires removal of the spacer bars and edge seals; and consists of limitations on processing. The glass unit itself has a higher life expectancy but must be frequently replaced due to edge sealants that have a shorter life span	Mass of the glazing = 236 (Frame- unknown)	

Table 24.0 Categorization of material output from building materials

Concluding the above study, based on the connection types:
Theoretically reusable/ recyclable material per m2 = (17572 + 8098 + 520 + 236) / 64,84 = 408 kg/m^2
Waste material per m2 = (7781 + 1459)/64,84 = 143 kg/m^2
Unknown end of life = 15 kg/m^2

6.3.7 CONCLUSION

Using the assessment framework, the extent to which Case 02 has incorporated high energy performance and circularity measures can be determined.

In terms of the building design,
In total, 566 kg/m^2 of materials is required for the structure and skin of the building (assuming a building life of 75 years), out of which 8 kg/m^2 is reused (directly or otherwise) or recycled (up) after technical life of the component has ended. This represents merely 1% of the total material input.
The main contributors to the material input in the building are the load-bearing structures, accounting for 396 kg/m^2, in the form of sand-lime masonry facade and reinforced concrete floors. These materials are downcycled at the end of life due to the nature of the material itself and filled connections used. Therefore, 70% of the material input is downcycled at end of building life.

According to the analysis, it is seen that 143 kg/m^2 of the materials ends up as waste, which can be either processed for incineration to produce energy or could end up in a landfill. Waste represents 25% of the material input here.

Due to insufficient data on the exact specifics of the remaining materials used, it is attributed to being unknown in this study and not included in determining the degree of circularity.

Summing up, it is known from research that the building was designed with high circular ambitions. Most of the materials used in the building is of secondary nature and bought off the Dutch Marktplaats. As specifics on this is not known, it is not taken into account in the analysis. What is seen however is that the building uses and incorporates circular measures in the form of renewable and prefabricated materials that creates material savings. The main structural materials are not however renewable, and are downcycled at the end of life. This is an area of improvement in the design.

In terms of energy use (input + reuse + output), 95% of the energy used in the building is generated on-site by a combination of renewable energy installations. The distinguishing system between cases 01 and 02 is the extensive use of wood and pellet stoves in case 02. These stoves use a renewable material (wood) for producing energy however, the output from the production is wood ashes. The circularity of such systems need to be further studied to determine if this is a circular practice.

While the building does not produces surplus energy to be returned to the grid, it does store all thermal energy to be used as demand arises, and also mitigates carbon emissions by using a fine dust filter.
The above analysis and conclusion is represented schematically in Figure 37.0.

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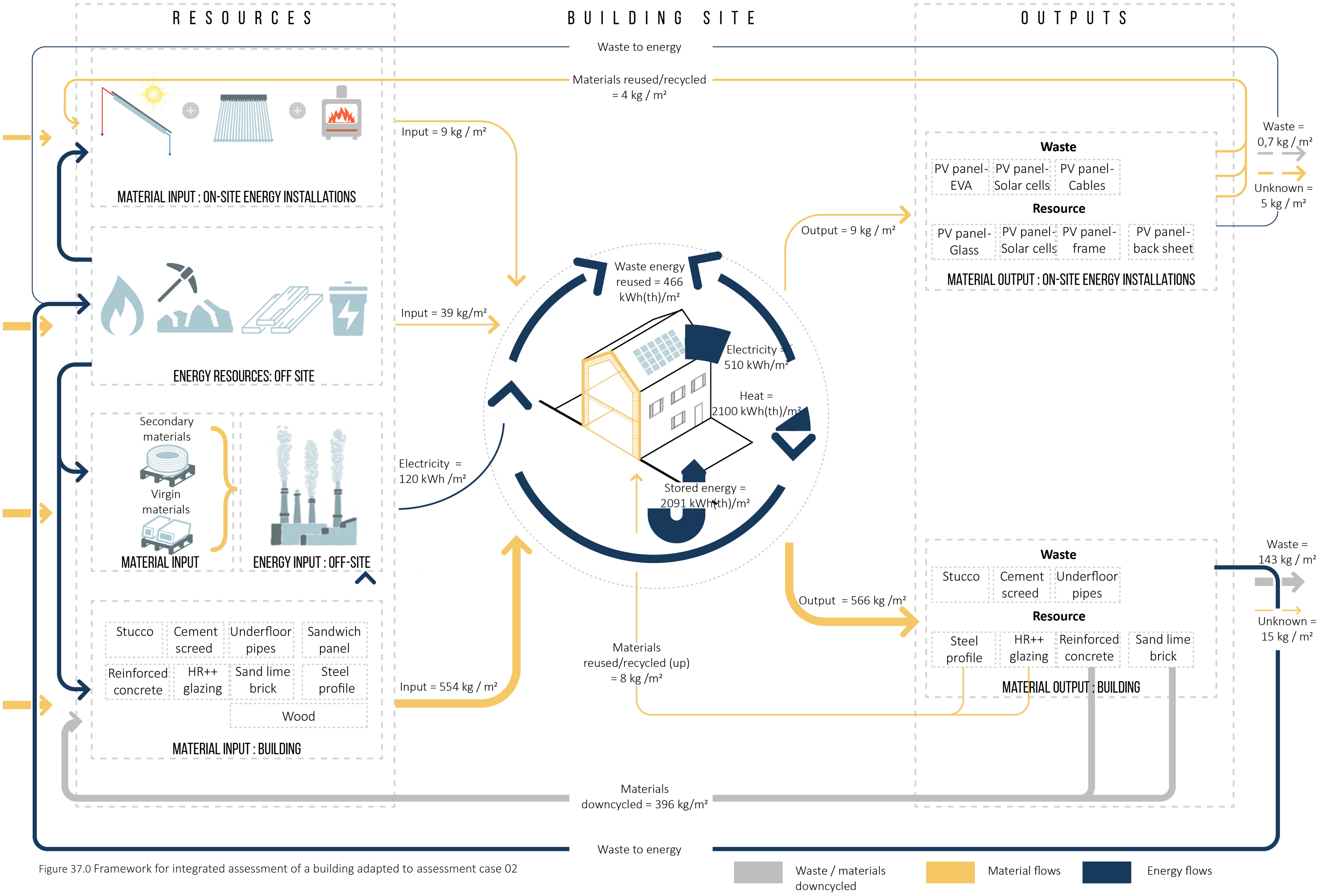


Figure 37.0 Framework for integrated assessment of a building adapted to assessment case 02

6.4 COMPARATIVE ANALYSIS

As cases 01 and 02 are of similar scale and building typology, they can be compared to understand the synergies and trade-off's between energy and circular flows, therefore shedding light on the interpretation of circularity in these buildings.

The trade-off's that arise in the design of a both energy efficient and circular building are explained as follows:

(a) Energy input & building material input: An evident trade off between energy input and building material input is seen in these buildings (figures 38.0 & 39.0). Between the two, case 02 has a lower energy demand which is facilitated mainly by on site generation of thermal and electrical energy. This reduced energy demand is achieved by a thick building envelope, specifically, incorporating more thermal mass in the floor (Rc value >=6,5 m²K/W). As stated in the assessment framework, the quantity of material input in a building should be judged based on the theoretical reusability of the materials after use in the building. From figure 39.0, it is seen that a large fraction of the materials used in the case 02 is downcycled at the end of life. The materials in question here are reinforced concrete, sand-lime brick and laminated glass. The non-circular end of life of these materials are as a result of the current recycling limitations for these materials. Although precast reinforced concrete creates effective material savings during construction, it cannot currently be recycled while maintaining its quality and strength. Similarly for the other two materials.
Creating a higher mass in the building to increase thermal resistivity is an acceptable passive measure to reduce energy demand (as understood from literature review), however, the end of life scenario of used materials should also be a design consideration taken into account.

(b) Energy input and energy resources: While it may appear that the material use for on-site energy installations for case 01 is far less than case 02 (see figure 40.0), the comparison here is not accurate. Case 01 has a high reliance on externally delivered energy, the material use for which are not within the scope of this study. Therefore, what can be compared here are the energy resources for the production of the energy input (figure 40.1). It is known that case 02 relies mainly on on-site energy generation to meet the building system demands. The technologies used are PV panels, solar collectors and biomass stoves. The energy resources for these systems are all renewable, namely solar energy and wood. The degree of circularity attained with the use of wood cannot be accurately determined, because although the end product of the thermal energy generation is wood ashes, it is not known if further treatment is done to the ashes to give it a circular life. And the same is not known about the filtered carbon emissions.

In Case 01, there is a large input from external sources (electricity grid and district heating). In the development within which this building is situated, the source for district heating is energy from waste incineration. According to the definition of a circular building in this research, resources must be indefinitely cycled at a high grade, therefore, the district heating input cannot be considered a completely circular input although it may also include off-site generated renewable energy. Furthermore, from figure 41.0 it can be seen that the sources for off-site electricity generation is also not completely based on renewable energy systems. Therefore, the preliminary assessment of the energy and material inputs in these two cases show case 02 having a more circular system as compared to case 01.

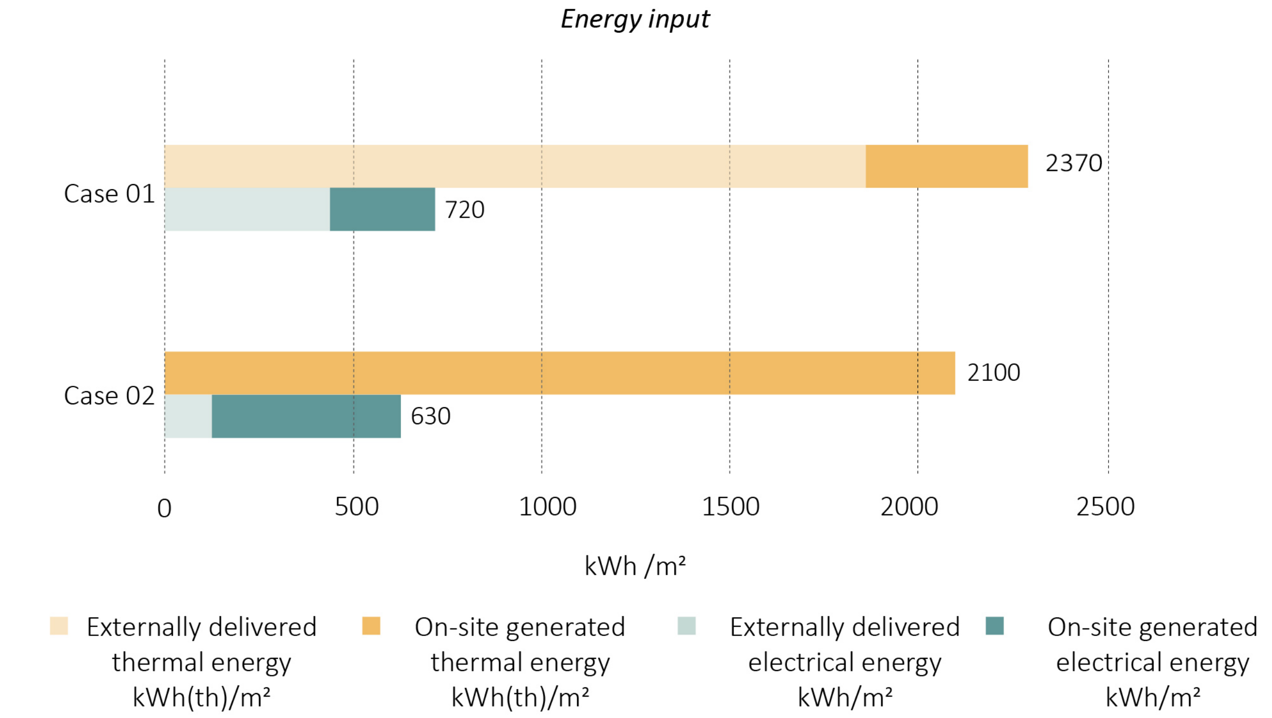


Figure 38.0 Thermal and electrical energy input of cases 01 and 02 (within a 30 year time period).

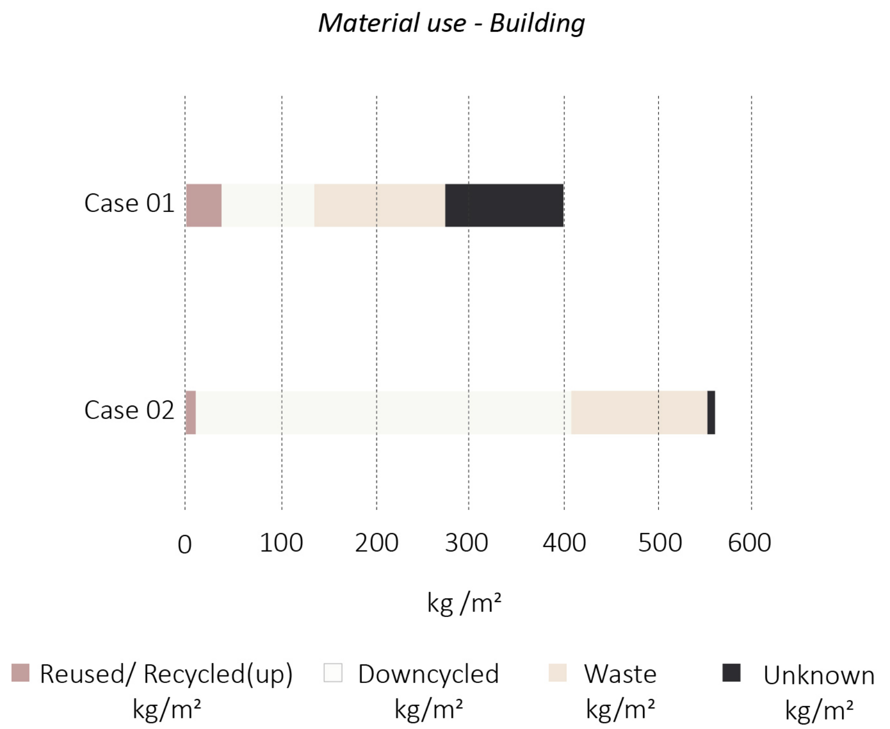
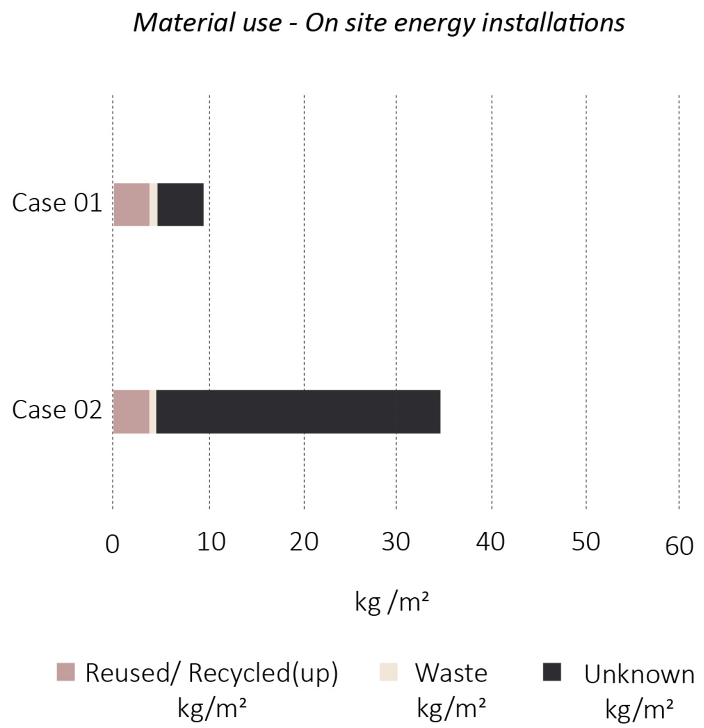


Figure 39.0 Building material input in cases 01 and 02. (within a 75 year time period)



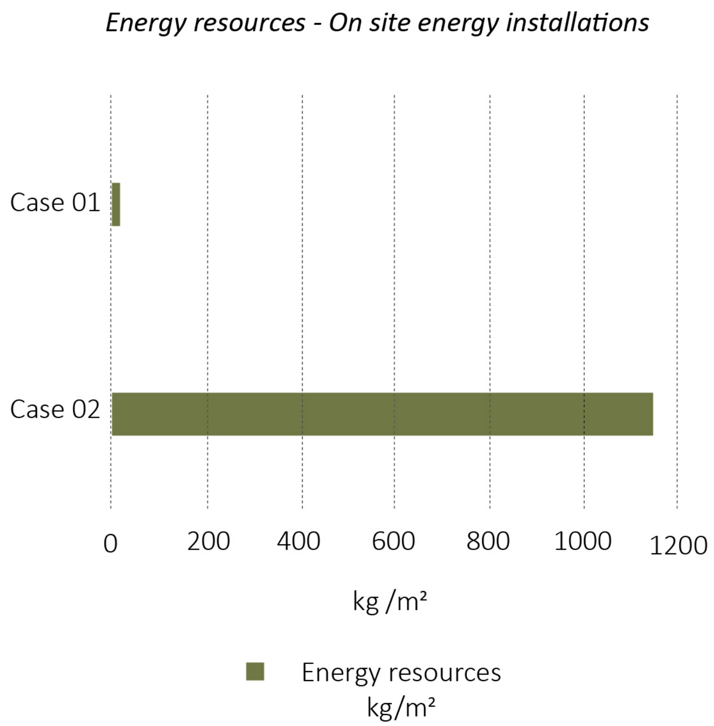


Figure 40.0 Material input for on-site energy installations (within a 75 year time period)
Figure 40.1 Energy resource input for on-site energy installations (within a 30 year time period)

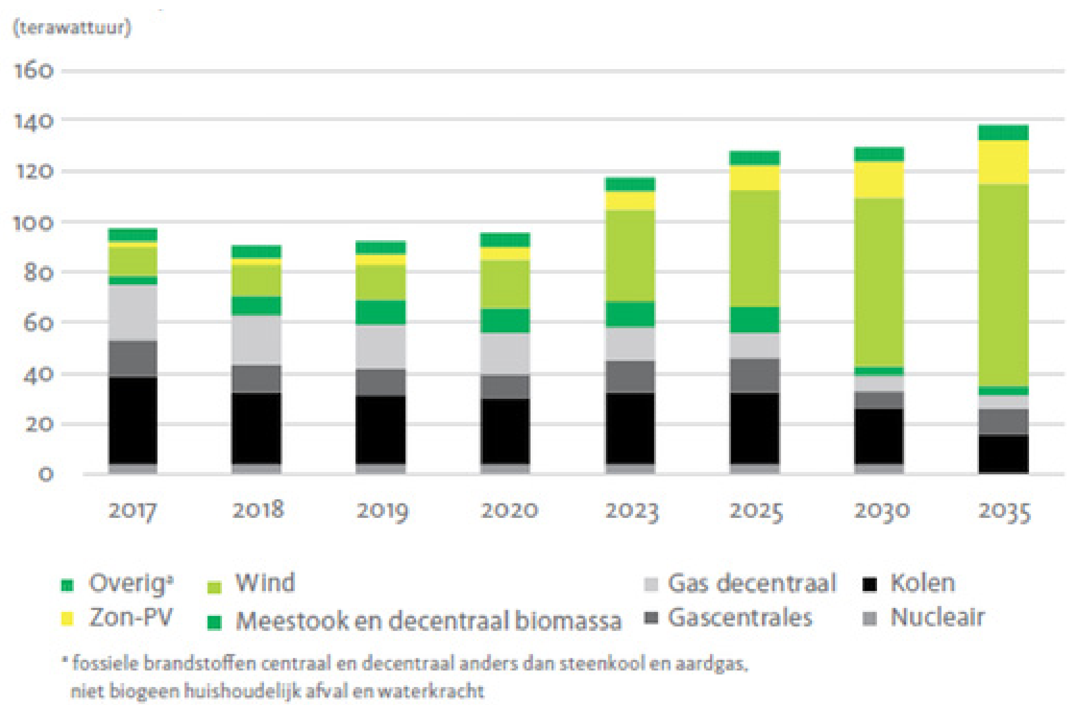


Figure 41.0 Composition of resources used for electricity production at district level *(ECN and CBS, 2017).*

(a) Energy resources and emissions: Owing to the type of resources that are used for the generation of energy to meet the building system demand, a by-product is the release of emissions. As seen from figure 42.0, case 02 combats the release of these emissions by applying a fine dust filter in the building. The emissions of case 01 are partly released outside the building site as the energy is externally delivered. In such a case therefore, it is not possible to have control over the quantity of emissions released. However, making circular design decisions such as only choosing energy systems that have a low environmental impact / connect to a system that uses only renewable resources can make a positive difference.

The synergies noted in the design of an energy efficient and circular building are:

(a) Energy input and waste energy reuse: As seen from the literature review, the energy demand attributed to the functioning of a building can be reduced by passive and active measures. Passive measures such as air tightness and heavy thermal mass directly impact the material use of the building. A circular measure that further reduces the quantity of energy input required within a building is the reuse of waste energy (such as ventilation and shower heat). Case 01 and 02 both incorporate the reuse of the internal waste, and as can be seen from Figure 43.0, this is can have a significant impact on the material input.

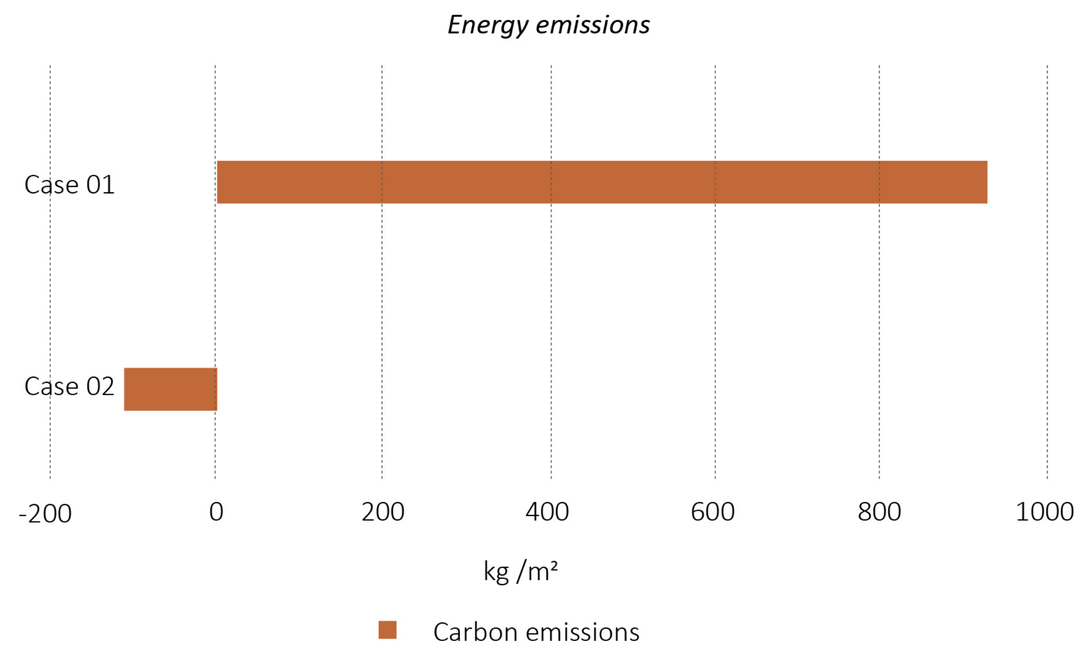


Figure 42.0 Energy emissions from cases 01 and 02 (within a 30 year time period).

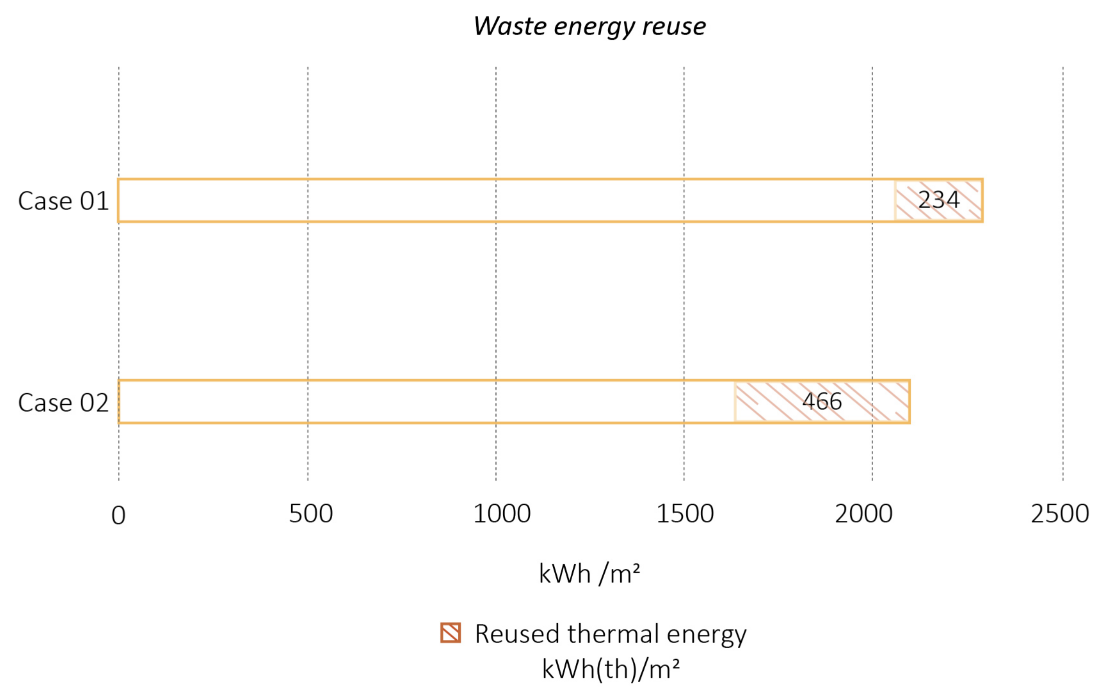


Figure 43.0 Waste energy reused in cases 01 and 02 (within a 30 year time period).

6.4 ASSESSMENT CASE 03

6.4.1 BUILDING DATA

Image source:Gaaga Architects

Case 03 is a ground + four storey apartment building, which is under construction since 2018. The apartment has a BVO of 1500 m^2. Following the same format of Case 01 and Case 02, the building information of this building has been gathered using a questionnaire. The response by the resident to the questionnaire is included in Appendix E (Section 12.5.1), and all subsequent gathered building information is included in Appendix E (Section 12.5.2 to 12.5.5).

The energy performance data of this residential building (based on the questionnaire) is summarized as follows:

EPC	0,15
External energy source(s)	District heating
Space heating source(s)	District heating
Space heating distribution network	Underfloor heating
Domestic hot water source(s)	District heating
Shower heat recovery	Absent
Ventilation system	Natural supply and Mechanical discharge (Type C)
Ventilation heat recovery	Absent
Active cooling system	Absent
Energy installations on site(s)	PV Panel
Peak power (PV panel)	17670 Wp
Green roof	Present

Table 25.0 Energy performance data of case 3. (More details in Appendix E (Section 12.5.1))

The building material data is summarized as follows:

Ground floor	
Structural material	Prefab concrete with demountable connections
Insulation	EPS (Rc- 4,0 m^{2}K/W)
Finishing	Unknown
Additional layer	Underfloor heating system
Use of renewable material	Yes
Demountable connections	Yes- Peikko system

Facade	
Structural material	Prefab concrete (columns + walls)
Insulation	Rock wool (Rc- 4,5 m^2K/W)
Finishing	None
Additional layer	Secondary wood: Azobe of old sheet pile profiles, untreated (fire class B), wooden posts (+ removable steel frames)
Glazing	Double glazing (Uvalue- 1,0 m^2K/W)
Use of renewable material	Yes
Demountable connections	Yes

Table 25.1 Building material data of case 3. (More details in Appendix E (Section 12.5.1))

Using the detailed indicators as elaborated in Section 4.2, in a manner similar to the assessment of case 01 & 02, the energy and material flows of this building can be quantified. The calculations are explained as follows:

6.4.2 INDICATOR 1 : ENERGY INPUT

The calculation of the energy input is divided into two:
Part 1: Externally delivered energy (Thermal + Electric) / m^2 / year

According to the Uniec calculation, the total electricity use in the building is 31839 kWh/year, of which 9934 kWh/year is generated on own site (op eigen perceel opgewekte elektriciteit). Therefore externally delivered electricity = 31839-9934 =21905 kWh/year. Table 26.0 shows the calculation in the format specified in Section 4.2.2.

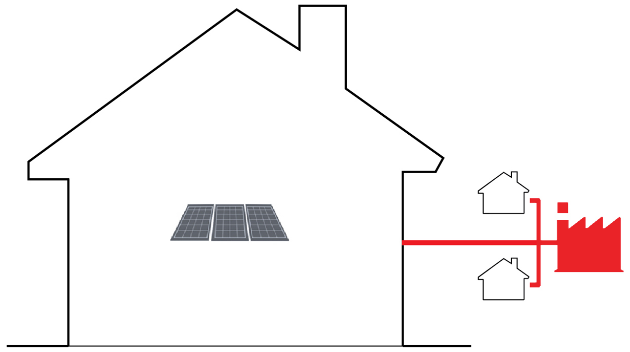


Figure 44.0 Overall scheme of the building with external and internal energy input (case 03)

Type of energy	Type of function	Supply source	Primary energy use (kWh/year)	Primary energy factor	Delivered energy (kWh/ year)	Carrier	Area (m^2)	Delivered energy per m^2 (kWh/m^2/year)
Electricity	Misc.	Electricity grid		2,56	21905	Renewable + Non-renewable	1500	= 21905/ 1500 = 15,0

Type of energy	Type of function	Supply source	Primary energy use (kWh(th))	Primary energy factor	Delivered energy (kWh(th))	Carrier	Area (m2)	Delivered energy per m^2(kWh(th)/m^2)
Heat	Domestic hot water	District heating	-	1,0	26842	Renewable + Non-renewable	1500	= 26842 / 1500 = 20
	Space heating			1,0				
Cold	Summer comfort			0,83				

Table 26.0 Calculation of delivered energy (kWh/m^2 / year)

The total externally delivered energy /m^2/ year is

$$= \frac{\text{Externally delivered thermal energy (kWh(th)/year)}}{\text{Usable area}(m^2)} + \frac{\text{Externally delivered electric energy (kWh/year)}}{\text{Usable area}(m^2)}$$

= 20 + 15
= 35 kWh /m^2 / year
= 1050 kWh /m^2 / year *(for 30 years)*

Part 2: On-site generated energy (Thermal + Electric) / m^2 / year
Similarly, the on-site generated electricity can be summarized as follows:

Type of energy	Type of function	Supply source	Primary energy use (kWh/year)	Primary energy factor	On-site generated energy (kWh/year)	Carrier	Area (m^2)	On-site generated energy per m^2 (kWh/m^2/year)
Electricity	Misc.	PV panels	-	-	9934	Renewable	1500	= 9934 / 1500 = 7

Table 26.1 Calculation of on-site generated energy (kWh/m^2 / year)

The total on-site generated energy /m^2/year is

$$= \frac{\text{On-site generated thermal energy (kWh(th)/year)}}{\text{Usable area}(m^2)} + \frac{\text{On-site generated electric energy (kWh/year)}}{\text{Usable area}(m^2)}$$

= 7 kWh /m^2 / year
= 210 kWh /m^2 / year *(for 30 years)*

6.4.3 INDICATOR 2 : MATERIAL INPUT (ON-SITE ENERGY INSTALLATIONS & BUILDING)

According to the questionnaire response, this building has installed 93 m^2 PV panels on-site. Using the general material specifications (See section 5.2), the material input of this installation can be calculated as:

Step 1: Determining the environmental load (= MPG score) of the system.
Using MRPI-MPG software, the MPG score is calculated as 0,14.
**See appendix E for calculation reference*

Step 2: Determining the initial material input of the installations :

Initial material input(kg) = Density of material (kg/m^2) x Installation area (m^2)
Similar to Case 01 (see Section XX, Table XX), the initial material input is calculated 1057 kg.

Step 3: Determining the additional material input of the installations :

Additional material input(kg) = Initial material input (kg) x Replacement frequency
Again, following the same method of calculation as Case 01, the additional material input is calculated as 2113 kg.

Therefore, the Total material input /m^2 = $\frac{\text{Total material input (kg)}}{\text{Usable area of the building}(m^2)} = \frac{1057 + 2113}{1500} = 2\ kg/m^2$

To determine the circularity of this material input indicator 5 is used. Due to lack of sufficient data the calculation of material input for the building is not conducted in this study. Therefore, in this case only the energy installations have been studied.

6.4.4 INDICATOR 3 : ENERGY REUSE

Based on the questionnaire response, it is seen that heat recovery systems have not been employed in this building. Using Uniec2,2, the quantity of waste heat that is unused can be estimated (See Appendix E, Section 12.5.3) for the calculation). In this case it is considered as an energy output and is calculated in Indicator 4.

6.2.5 INDICATOR 4 : ENERGY OUTPUT

In this building, there are two types of energy output: Carbon emissions and unused waste energy. The carbon emissions of the building is derived from Uniec as 5 kg/m^2/year (or 150 kg/m^2 for 30 years) , However it is not known if any measures to process these emissions have been applied.

The quantity of unused waste heat from the shower heat and ventilation system is calculated using Uniec in the following manner:
1. The calculation is replicated.
2. System variant of the ventilation system is changed to mechanical ventilation with heat recovery and shower heat recovery is applied in the building.
3. The difference between the original and modified calculation is noted.

The result is a difference of 64855 - 50987 MJ = 13868 MJ
= 3852 kWh(th)

Total energy output /m^2/year = $\frac{\text{Total energy reused (kWh(th))}}{\text{Usable area of the building}(m^2)}$ = 3 kWh(th) / m^2/ year

= 90 kWh(th) /m^2 / year ***(for 30 years)***

6.3.6 INDICATOR 5 : MATERIAL OUTPUT

The material output from on-site energy installations:

Using the literature review of energy installations, elaborated in Section 5.2 & 5.3, the circular (reused/recycled) and non-circular (waste) output of on-site installations can be determined in the same manner as Case 01 (Table 19.0).

Summarizing the assessment of on-site energy installations with reference to the usable area of the building:

Theoretically reusable/ recyclable material / m^2 = 2 kg/m^2
Waste material / m^2 = 0,3 kg/m^2

6.4.6 CONCLUSION

Case 03 cannot be assessed to the same extent as case 01 and 02 due to the lack of quantitative data. The building is still interesting to assess as it an apartment block that has interpreted circularity in terms of demountability. This information is known through a questionnaire distributed (Appendix E).

In terms of energy use, it can be seen that the building only produces electricity on site through the installation of 93 m^2 of PV panels. The remaining demand is met by district heating, the sources of which are not purely renewable. The waste streams within the building has also not been utilized. It is interesting to therefore, see through qualitative data that this apartment has prioritized circularity while meeting the energy performance demands set by the EU (Seen in Appendix E).
The known energy and material flows have been summarized in Figure 45.0.

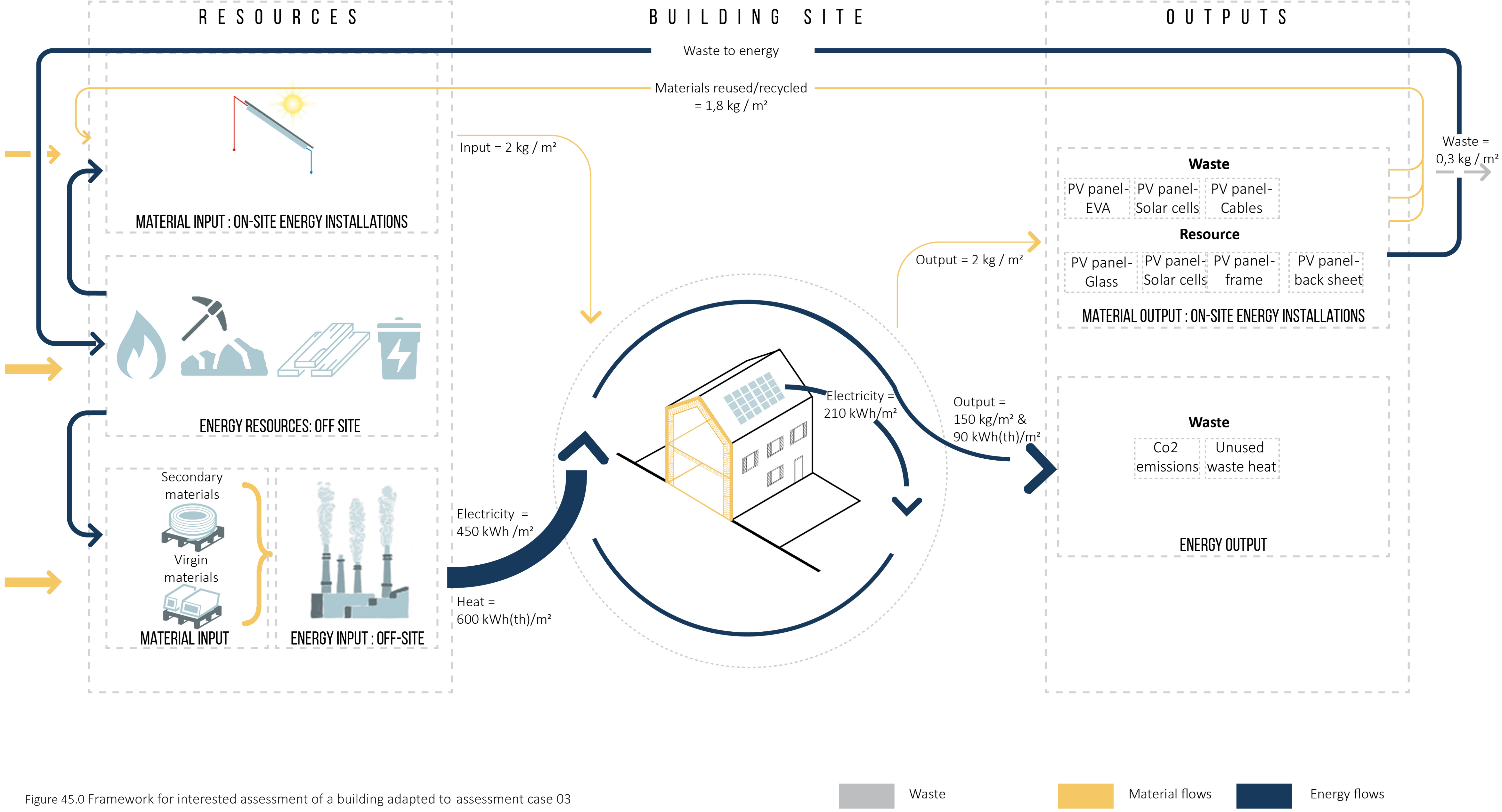


Figure 45.0 Framework for interested assessment of a building adapted to assessment case 03

5.6 CONCLUSION

DESIGN BY RESEARCH

5. To what extent have high energy performance and circular principles been combined in the case study buildings? Are there synergies and/or incompatibilities?

The assessed buildings have been designed with very high ambitions. The buildings are located in a neighbourhood that developed a circular manifesto for itself, that pushes the development to meet the goals of energy performance and circularity set by the Dutch government and the EU.
To achieve a highly energy efficient and well performing building, extensive standards and methods are available. And owing to this, the assessed cases have incorporated multiple measures that resulted in a well performing building in terms of energy. This has been done by generating a high share of energy on-site by renewable sources, reusing waste heat and intentionally storing on-site generated energy so that it can be used as demand arises.

The interpretation of circularity however is not as straightforward, and have been interpreted to different extents in the assessed buildings. It is important to note and acknowledge that these buildings have considered circularity as an integral part in the design and have applied measures especially accounting for the MPG of materials (according to questionnaire responses). However, it is seen that when a trade off is made, energy performance has been prioritized. This can be attributed to the fact that this performance can be quantified, and is strictly regulated in the EU, while the same has not been applied for circularity.
In this research, the extent is determined by the integrated assessment framework in which five indicators have been defined. From the available data it can be seen that circularity was considered in the design of the building, which translated into the use of renewable materials, prefabricated components and opting to limit the use of insulation. Therefore, the 'intention' is in place. An accurate estimation of the extent of circularity cannot be determined due to lack of sufficient data.

The assessed case 02 is an especially interesting building that has combined energy and circular principles well. The building relies almost completely on on-site generated energy using PV panels, solar collectors and wood stoves. The use of wood stoves is tricky as it is an efficient energy producing resource and uses renewable materials to produce the same. Therefore, it is both energy efficient and circular. One drawback is that is creates two types of output- wood ashes as material output and carbon emissions are energy output. This building has installed a fine dust filter to capture the emissions therefore combating one negative output. The outcome of the wood ashes is not known.
While this is only one case and not representative of all new buildings, the other cases studied have also attempted to design with such high ambitions.

In terms of synergies and trade-off's, the obvious synergy is the reuse of internal waste heat of the building. The trade-off's are also interesting to note. An evident trade-off (clearly visible in case 02), is the reduction of energy demand facilitated by a massive building envelope. It cannot be immediately assumed that this is non-circular, because as mentioned previously the theoretical reusability of the materials is the determining factor. Upon further study it was concluded that the majority fraction of the materials used is non-circular, therefore this was a trade-off.

07

This section answers the following sub-research questions:

5a. What are the design guidelines that can be developed to improve the integration of circular and energy efficient design in the case study buildings?

6. How can the selected case be improved to better combine high energy performance and circular principles and achieve greater synergy between them?

Aim of research: Provide feasible (in the short and long term) improvement strategies which can be implemented in the design phase of new buildings to achieve greater coherence between the energy performance and material circularity.

7.1 GENERAL DESIGN GUIDELINES

Certain circular ambitions are set within the detailed indicators of the integrated assessment method, based on which the case studies are assessed. From the results of these assessments, what is seen is the intentional use of multiple circular measures to meet a set out ambition. Lessons can be learnt from these cases and formulated into a set of design guidelines for designers, self-builders or owners to follow. The intention of these guidelines is to achieve increased coherence between energy performance and circular measures in building design.

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Furthermore, while designing a building, certain factors that affect the energetic/circular performance are within the control of the designer (and within the system boundary chosen in this research), while certain other crucial factors are beyond control. Therefore, the guidelines are also divided into two:

Step 1: Design choices to be made within system boundary.
Step 2: Overarching design choices outside the system boundary impacting the degree of circularity of a building.

STEP 1 : WITHIN THE SYSTEM BOUNDARY

Certain circular decisions can be made during the design phase that impact the overall degree of circularity of the building during operation and extending to the end of life of the building. These decisions fall within the created system boundary and are as follows:

To meet the energy demand of a building in a circular manner, three aspects of the energy input must be considered:

(a) Energy resource: In accordance with the principles of a circular economy, the resources used for energy input should be renewable, such as solar, wind, biomass energy (etc). The possibility to generate this energy input on-site must be explored first, before considering external delivery. Making circular choices about the inputs and outputs of on-site installations are within a manageable scale for the designer and should be preferred over a larger district system. In cases where site conditions limit the generation of energy on-site, external delivery using renewable energy resources can be preferred.

(b) Supply component: As stated in Section 4.1.4, in order to create and maintain a circular building, designers and users must be aware of the sourcing and end of life possibilities of the materials that go into the building, including the material use in energy systems (on-site and off) so that a positive change can be instigated. Therefore in addition to maximising the efficiency of a renewable energy system, the decision on using a certain energy installation on site should come with a background check on the end of life scenario of the installation.

For example, comparing two popularly used PV panels in buildings, a typical monocrystalline module is seen to have a higher weight to power ratio (Figure 46.0). In comparison, thin film technologies are more efficient in terms of weight ratio. However, CdTE (the most popular thin film technology) contains significant amounts of cadmium, which is an element with relative toxicity, and presents an environmental issue worldwide *(Access, 2018)*.

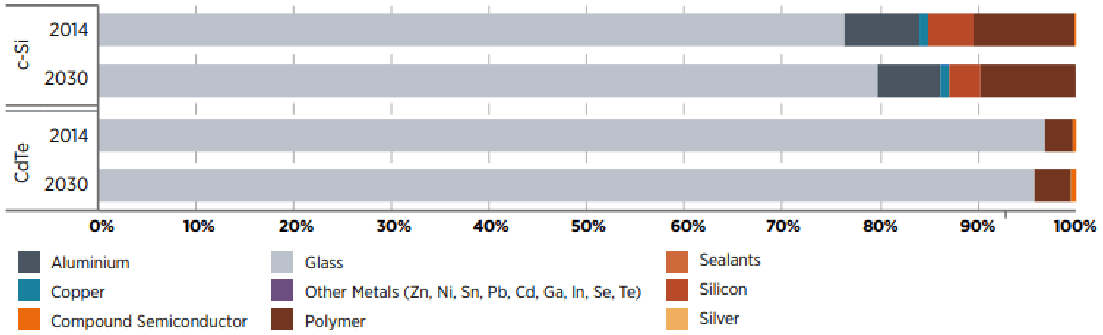


Figure 46.0 Impact of innovations in PV technology on material composition *(IRENA, 2016)*

To increase the circularity potential of an individual building, the circularity of individual components such as these must also be considered, although the design of these lies within the scope of the manufacturer and value chain partners.

(c) Output: According to the new stepped strategy (referred to in this research), all waste generated from a system must be reusable as 'food' in some form. Design choices of the energy system should take into account the output generated from the system. Looking to the case study assessment as an example, in case 01 there is a considerable energy output created as a by product of the connection to district heating. In case 02, the heating demand in the building is met by an on-site biomass stove, which also generates carbon emissions as an output. However, in this case the emissions were controlled using a fine dust filter on site. While this is one option for a partial circular intervention, and generally it should just be noted that emissions should be reused as much as possible so that no waste is generated as a result of the building design. In the case of a biomass stove, this can be done by prioritizing the use of waste wood as the energy resource and other operational measures such as ensuring complete combustion in the stove and installing a secondary air system.

This guideline also extends to the reuse of waste heat in a building, as it is an internal waste created during the operational phase. The reuse of waste heat can considerably reduce the energy demand of a building (as depicted in Figure 42.0, Section 6.3).

To meet the material demand of a building in a circular manner, five aspects of the material input must be considered:

(a) Type: While the materials used in a building may be virgin or of secondary nature, within the framework of a circular economy, all materials used must be non-hazardous and not scarce in quantity. The indefinite cycling of a hazardous material is not considered circular.

(b) Source: Similar to the guideline for renewable energy resources in a building, the source for materials in a building must also be renewable. The renewability of the material must also be in accordance with the type of material and must reused/recycled within a time period appropriate to the human scale.

(c) Quantity: The quantity of materials used in a building can be influenced by multiple factors, ranging from passive design strategies to increase thermal mass (and reduce the energy demand), to potential over-dimensioning of components to account for changes in the future. Such a decision should also be influenced by the extent to which the material can be reused or recycled(up) at end of use life. For instance, the use of standardized component sizes makes it more likely that a material is reused at the end of its use life in the building. In other cases in which the material has limited reusability, the quantity used should also be restricted.

(d) Composition: Three factors should be taken into account while designing the composition of a heterogeneous element or component. The factors are:

i. Assembly sequence : The assembly sequence of a component must be coordinated with the life cycles of constituent materials in the component. Which means elements with the shortest life cycle must be assembled last, while elements with the longest life cycle in comparison must be assembled first. Such a sequence is known as Parallel assembly, as explained by Elma Durmisevic (Figure 15.0, Section 2.2.5).

ii. Treatments : The application of irreversible chemical treatments to materials (such as laminating glass for example), limits the high grade reuse/recycling of the material at the end of use life. Conscious decisions must be made to apply reversible treatments, or design in a manner that the material can be reused directly after use. For example, insulated glass has a higher life expectancy compared to the sealants used in a window. Direct reuse of the glass (which is treated) instead of discarding for reversing treatments can be a better option.

iii. Connection type : Circular use and indefinite reuse of materials is facilitated by using demountable connections between materials and elements. Demountable connections can be one of the following:

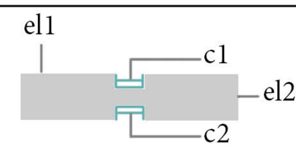
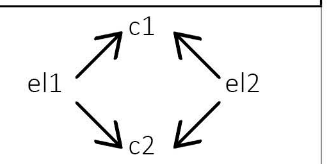
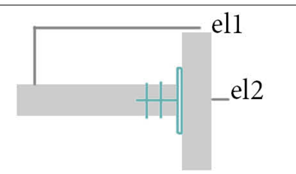
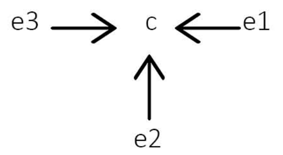
Type of connection	Reuse-ability / Recyclability	Dependence in assembly	
Indirect connection via independent third component	Yes reuse / Yes recycling		
Indirect with additional fixing device	Yes reuse / Yes recycling		

Table 27.0 Demountable connection types *(Elma Durmisevic, 2006).*

iv. Relationship pattern: Material replacement and maintenance can be easily carried out when materials have a open relationship pattern as opposed to closed. This is diagrammatically explained in Figure XX. In this type of pattern (open) damaged or worn out materials can be easily replaced without affected other materials in a composition.

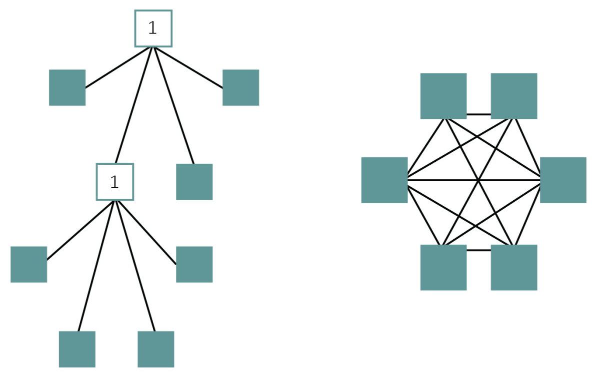


Figure 47.0 (left) Open relationship pattern, (right) Closed relationship pattern *(Elma Durmisevic, 2006).*

(e) Life cycle coordination: Heterogeneous components must be designed in such a way that the technical life of component matches the use life of individual materials. This ensures that when a component is replaced, all the constituent materials have reached end of life therefore separate tracking of the materials for reuse, recycling, refurbishment or remanufacturing need not be extensive. It is possible that this cannot always be done, and in such cases individual materials must be tracked to ensure it undergoes the appropriate circulation.

(e) Output: The currently possible end of life scenario as per available technology for materials used in the building must be checked in the design phase. It was seen from the case study assessments that although factors facilitating easy disassembly and reuse were incorporated, current recycling technologies prevented high grade reuse/upcycling of the material leading to downcycling. Therefore, during the use life of the building, materials must be reused and maintained until the end of its individual use life has been reached, after which high grade upcycling options must be explored.

Trade-off between factors:

Passive design: As mentioned previously, passive design strategies to reduce the energy demand of a building can influence the quantity of materials and treatments done to the same. A trade-off generally done in buildings is the use of air tight (and therefore non-demountable) connections to avoid thermal bridges between building layers. In such cases, an open hierarchy with specification of a base element can be a plausible circular design measure (Figure 47.1).

As elaborated in the literature review (Section 2.2.5), base element specification allows for easy repair and maintenance of materials without disturbing other materials. When fixed or direct connections are unavoidable, such a system can ensure that the irreversible connections are limited and does not largely affect the disassembly of the whole component.

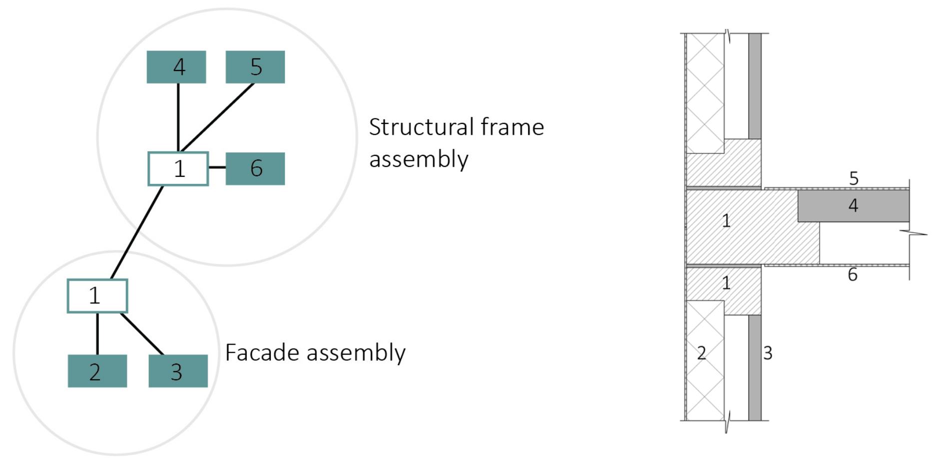


Figure 47.1 (left) Open assembly with base element specification between two building assemblies *(Elma Durmisevic, 2006).* (right) Example of connection detail between structural frame and facade assembly

STEP 2 : BEYOND THE SYSTEM BOUNDARY

While the designer or user may have significant influence on some design decisions within the system boundary, other overarching design choices outside the system boundary can also affect the overall circularity of the building. Conscious circular choices in the following factors can ensure that a positive footprint is left behind.

(a) End of life scenario: While the choice of an on-site energy installation is made keeping in the mind the materials used in the component, it must also include an understanding of how the installation is discarded when technical life has ended. Currently stringent regulations are being put in place by the EU to minimise the waste created from PV technologies. Treatment of waste generated from other technologies (such as solar tubes, ATES, heat pumps etc) might not meet the same standard and should be a contributing factor in the choice of installations.

(b) Material input: It must be noted that any connection to external systems comes with a hidden material demand and therefore material input at different levels. For instance, in a district heating system the distribution network includes the heat substation, storage units, distribution channels and emission technologies, which might not all be designed in a circular manner.

In addition to these factors, it is advised to conduct a life cycle assessment (Explained in Section 2.1.4), of the whole building. This gives an insight on the environmental impact of the building in terms of resource use considering the complete life of resources starting from extraction and ending in demolition.

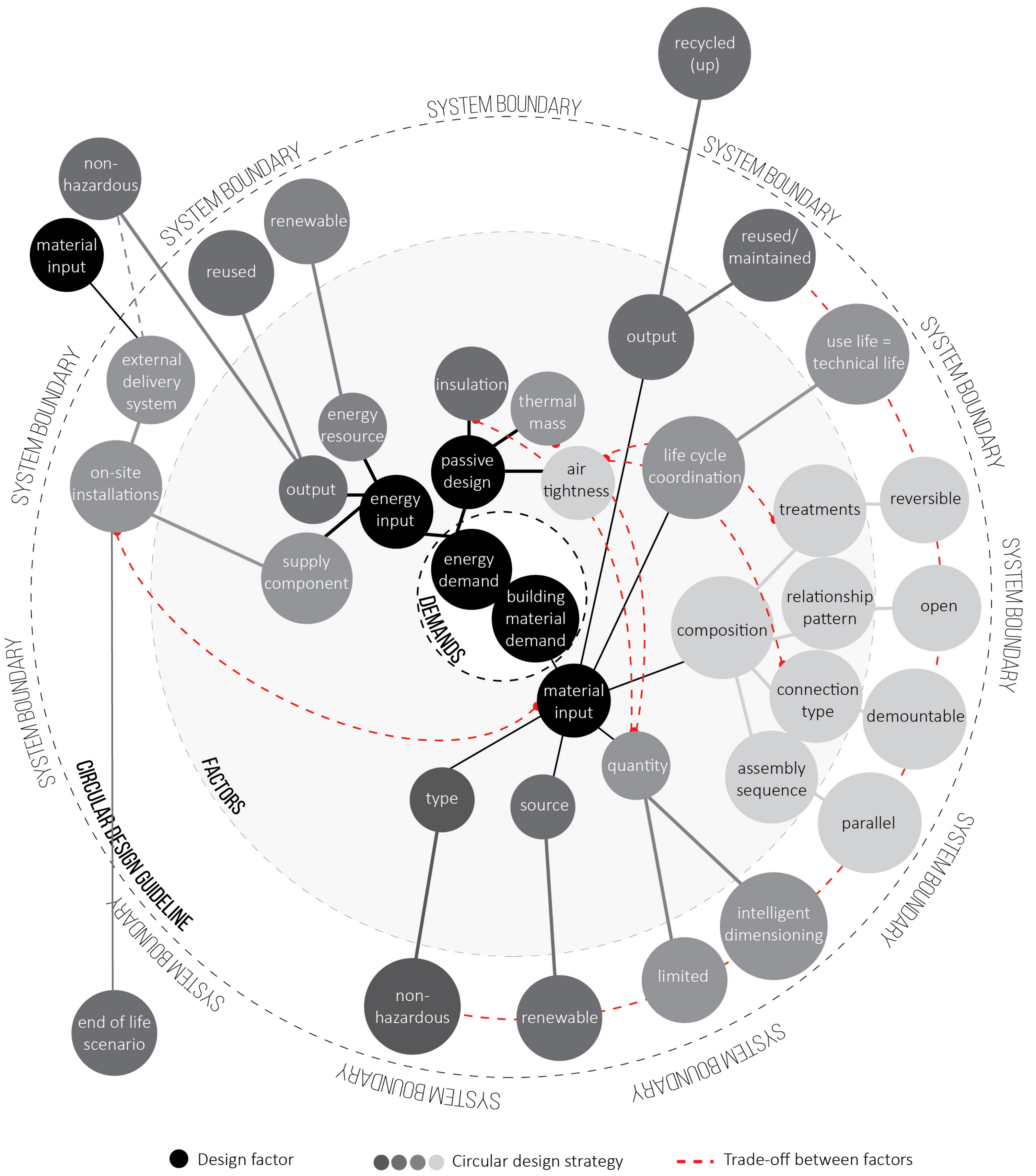
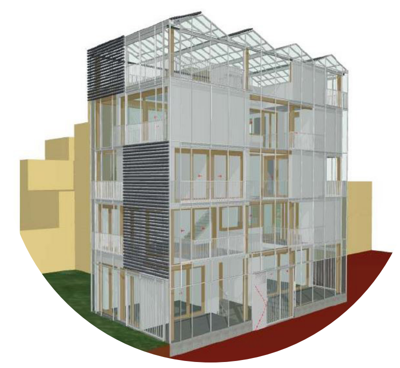


Figure 48.0 Overview of factors influencing the degree of circularity of energy and material flows in a building, and circular design decisions that can be made.

7.2 CASE STUDY DESIGN

The design guidelines elaborated in the previous section outline a few parameters that can contribute to designing flows in a circular manner. However, the design also involves multiple other complex parameters such as supplier influence, cost, local availability of resources, subsidies are more, therefore a design strategy for improvement cannot be directly proposed. Instead certain considerations can be made for the design phase of the building.

Using the assessment case 01, the following discussion areas are discovered that can be addressed to improve the design:



1. **End of life scenario:** Obvious circular aspects such as demountability, renewable resource use, waste reuse have been well addressed in this building. The quantity of materials used for the structure has also been optimised by using prefabricated elements (prefab hollow core slab). However, concrete as a material currently cannot be recycled (up) using existing technologies, which would lead to the downcycling of the structure at end of the building's life.

   Similarly, the insulated glass used in glazing would likely have use life remaining when it is replaced. The direct reuse of the glass should be considered as a priority before recycling is considered to avoid downgrading the quality of the materials.

   In addition to considering the end of life of building materials, the disposal of on-site energy installations must be looked into. Currently the building uses PV panels, evacuated solar tubes and biomass stove. Regulatory guidelines on the safe disposal and recycling of PV technologies are in place. Not much is known about the treatment of waste created from the biomass stove, but it should be noted that the output must be treated and reused appropriately. By incorporating this factor in the design phase, the building can be designed to better fit within the circular economy principles.

2. **Connection types:** Use of demountable (indirect/reversible) connections would facilitate increased reusability of materials at the end of life. For instance, the connections between structure and insulation material in the façade and ground floor could have been demountable so that easy maintenance and repair would also be possible.

3. **Energy supply component:** The supply source of district heating in the development area is from the incineration of waste. With the aim to create a circular economy in the Netherlands by 2050, the available quantity of waste for incineration in the future cannot be relied upon. On-site generation of energy should be prioritised with lower dependence on external delivery. Currently in the building only 48% of energy is generated on site.

4. **Energy output:** A consequence of the connection to external grid is the generation of carbon emissions as an output, the mitigation of which is beyond the control of a designer or user. Thus, referring back to point 3, on-site installations should be considered first, as it is possible to combat the on-site generated emissions by incorporating filters and other systems (similar to assessment case 02).

7.3 CONCLUSION

5a. What are the design guidelines that can be developed to improve the integration of circular and energy efficient design in the case study buildings?

Using the assessment parameters of the indicators in the framework, and analysis of the case study assessments the following set of design guidelines are developed. These guidelines aim to individually raise the circularity of energy and material flows within a building, and as a result improve the overall degree of circularity. The guidelines also address the trade-off's that may arise between the two flows and an understanding on how to tackle them. Furthermore, these guidelines are divided into two sets, based on the extent of influence a designer has in the named factors.

	Within the system boundary	Beyond the system boundary
Circular design guidelines	**For the material input of the building:**	
	1. Use non-hazardous materials. 2. Use renewable materials (in either biological or technical cycles). 3. Opt for intelligent dimensioning if future reuse is enhanced. 4. Assemble materials within a component in a parallel sequence. 5. Use demountable connections. 6.Create open connection patterns between materials. 7. Ensure treatments done to materials are temporary and reversible. 8. Coordinate use life of materials with technical life of the component.	1. Take into the account the possible end of life of materials based on current technology.
	For the energy input of the building:	
	1. Prioritize on-site energy generation. 2. All energy and material output created as a by-product on site must be reused. 3. Use renewable energy resources for energy generation. 4. Consider the energy resources used in external energy systems (is it completely renewable?).	1. Consider end of life scenario of the energy installations. 2. Take into account the emissions created off-site as a result of various energy resources used in external energy system. 3.Consider the material required for production to distribution of energy in an external delivery system.
	Trade-off's between factors:	
	1. Increasing the energy installations on site impacts the quantity of material input required for the building - Ensure installations are safely reused/upcycled after use. 2. Increase of insulation and thermal mass to reduce energy demand of the building leads to an increased material input in the building - Design for disassembly and reuse after use life considering the composition of the component. 3. Air tight envelopes for energy reduction leads to irreversible connections - Opt for base element specification and open relationship pattern.	
	Overall:	
	Conduct a life cycle assessment for the whole building, taking into account the circular life intended for materials and energy output after use in the building.	

Table 28.0 Overview of design guidelines

6. How can the selected case be improved to better combine high energy performance and circular principles and achieve greater synergy between them?

Upon analysis of the selected case 01, the following discussion points are developed, the improvement of which would lead to a better circular performance in the building:

(a) End of life scenario : It was seen that the end of life scenario of certain building materials with reference to the current recycling technology was not considered.

(b) Connection types : According to the collected data, irreversible connections have been used in the structure of the building. This can be opted out for demountable connections that allow for easy repair, maintenance and reuse, leading to an overall circular structure that is more easily adaptable and flexible.

(c) Energy supply component: Currently there is an energy input from district heating and electricity grid in the building. As there is possible room in the building to implement more on-site energy installations, this can be considered in order to reduce dependence on external supply (the energy resources of which can be unreliable).

(d) Energy output: A significant amount of output in the form of emissions is generated, possibly due to the connection to district heating. Meeting the demand with on-site installations and employing measures to combat resultant output is a viable option for design improvement.

D I S C U S S I O N

08

The aim of this research was to uncover the extent to which the current built environment has already advanced towards a sustainable environment in terms of energy and material use. The method adopted to do this was a framework, developed especially for this study. As one can imagine, this means that there are multiple possibilities to improve the method to be more extensive and be applicable to more building design parameters. For this reason, it is interesting to look back upon and discuss (a) the assessment method, and (b) further reflect on other complex factors that currently pose as a barrier to creating a circular environment in the near future.

8.1 INTEGRATED ASSESSMENT METHOD

Measuring the energy performance of a building is relatively straightforward in comparison to measuring the circularity of a building. The availability of a standardized measurement criteria (EPC) enables grading and comparison of energy performances. However, the circular economy comes with no such standard, which is why multiple approaches can be taken. In this research, I believe that after gaining an understanding on the fast paced nature of energy efficiency in buildings, compared to circular designs, it was important to define radical goals and assessment criterion's. Thus, in reaching for the radical goals, conscious design decisions are instigated at a faster pace. In this process multiple conclusions were reached in the case study assessments , however, the level of circular ambition that these cases started off with must be acknowledged.

One of the many barriers to the adoption of a circular environment is the limited acceptance in shifting from traditional construction methods to new methods. The studied cases have invested in firstly, learning and implementing circular choices, and secondly, sharing the acquired knowledge in order to help others join the movement. This has allowed for the testing of the created integrated assessment method which is a step towards conducting complete circular assessments of a building. From the testing, loop holes were discovered, which is uncovered in the following sub-section.

8.1.1 SUGGESTIONS FOR IMPROVEMENT

After testing the assessment method on the three cases, the following improvements are proposed to the method:

1. The material input indicators currently address the use of two types of materials- Virgin and secondary, however due to the lack of substantial data, the impact of secondary material use on the overall circularity of the building could not be assessed. Therefore, as an improvement a sub-method to identify such circular decisions and reward it within the method can be made.

2. The calculation for additional material input in indicator 3 accounts for maintenance and repair during operation phase. Again, there should be a distinction made to acknowledge the use of materials that require relatively low maintenance and systems that are designed for easy repair.

3. Measures to reduce the energy demand (such as optimization of space plan) of the building as a priority has not be assessed in the method. It is noted that this is an important step in achieving a high energy performing building, however, its impact on the flows of the building are not addressed or assessed. This could be included in further refinement stages of the method.

4. Acknowledging and assessing the embodied energy of materials is an important aspect in order to determine the overall circularity of the building, for which a life cycle assessment must be conducted. This can be added to the method as a final step.

5. The framework mainly focussed on filling the gap between the energy performance and material circularity of a building. However, circularity and circular design does not only relate to materials and energy. It also includes Water, Health & well-being, Biodiversity & ecosystems, and Human culture & society, which can be included as follows:

a. Water:
By taking into account the reuse of internal waste (within energy flows), energy cascading is incorporated as an integral part into the framework. This can be further extended to include the reuse of internal waste water - treated grey water and collected rainwater for washing machines, dishwasher, etc. resulting in reduction of external supply of domestic water.

b. Health & well-being:
Taking measures to reduce/mitigate the environmental load of materials by virtue leads to a building design that embodies no or minimal toxicity.

c. Biodiversity & Ecosystems:
The previous also applies to biodiversity and ecosystems - by taking into account the environmental load and impact of the building design and constituent elements (energy and material use), a positive impact can be created on the ecosystem.

d. Human culture & society:
"Building design should lead to minimal social shortfall and loss of cultures through embodied and use-phase impact" (Gemeente Amsterdam, 2017).

8.2 SUGGESTIONS FOR FUTURE RESEARCH

In order to further the research conducted in this graduation project, and on a larger scale to further our movement towards a sustainable built environment, the following suggestions are made for future research:

1. Develop the integrated assessment method by extensive testing on various building typologies and track the design decisions that are currently a hindrance towards the adaptation of a completely circular building.

2. Develop a rating or scoring method for each of the indicators in the framework so that the degree of circularity in a building can be represented as easily as EPC or BENG. One of the limitations of the circular economy is the lack of a standardized tool by which a building's circularity can be immediately pinpointed. For instance, with the current regulation when building calculations are done, if the EPC value of a residential building is above 0,4 it is immediately known that the energy performance needs to be improved. The Dutch national building decree does not lay such standards for the environmental performance of the building. If a scoring method is created on the integrated assessment method it is already a step towards standardizing circularity.

3. Develop the framework into a plug-in tool for BIM programs so that the effect of design measures can be tracked in real time. In this way, if trade-offs take place between different flows, it can be tracked and addressed in the design phase. For instance, in Uniec the effect of using recovery units on the EPC is seen immediately, and similarly the environmental performance of the building due to the use of a heat exchanger should show up as a value beside the EPC to see if the recovery unit is a circular product.

8.3 LEGISLATIVE AND ORGANIZATIONAL BARRIERS

The implementation of circular economy principles in the built environment is slow. Despite the multitude of research conducted in this field, if certain legislative and organizational barriers are not addressed the complete transition from a linear to circular economy will not accomplished. It is therefore important to look at this bigger picture and address these barriers, which were witnessed in the assessment cases. Some of these are specific to particular products and sectors and requires action to be taken at the EU, National, Regional or local level accordingly. They are as follows :

1. As the organizational structure of a circular economy is vastly different from the current linear economy, new business models have to be developed to cater to the same. The aspects of these models such as subsidy payments and investment in waste and resource management at product level, act as incentives for designers and owners to adopt more sustainable practices. However, the costs involved in the R&D of these models are seen as a major barrier for especially small and medium sized businesses. In such cases, the social gains acquired in providing these subsidies must be factored in to the cost analysis. Subsidies on service oriented business models combats the lack of acceptance with respect to such models (for example facade leasing). This further leads to increased supplier responsibility to consider efficient resource utilization in products.

2. An aspect that possibly contributes towards the difference between having circular ambitions and actual realizations are supplier discounts (witnessed in the assessment cases). Providing pricing incentives to manufacturers and recyclers for efficient resource utilization and reuse from a National or Regional level (similar to regulations in place for PV recycling) could go a long way in circular decision making for designers, self-builders and owners.

3. The current situation of limited information and economic incentives in the supply and maintenance chain can be combated by creating an easily accessible market (and database) for secondary resources with key information about performance and environmental costs. This further leads to de-stimagitising the notion that secondary materials are under-performing.

CONCLUSIONS

09

This section will answer the main research question addressed in this research and one sub-research question unanswered in the previous sections. Conclusions of other sub-questions of this research are answered in detail at the end of individual chapters.

Main research question:
To what extent are high energy performance and circular ambitions combined and achieved in new buildings, and how can this performance be further improved?

The case studies analysed in this research are located in a development with high ambitions for energy performance and circularity; and only represent a minor fraction of new residential buildings in the Netherlands. Therefore the insight gained by the assessment cannot be generalized to determine the current extent in the built environment. The integrated assessment method developed in this research provides a pathway to determine this extent, which can be done so with iterative assessments. From a literature review it was seen that many tools developed to determine the sustainability or circularity of products/components are largely unused as they have not been tested empirically. By testing the method further with qualitative data from buildings, the method can also be further developed while gaining better insight into the built environment.

The basis for improving the combination of energy and circular ambitions in buildings, is by tracking the inflows and outflows of the building. Which means, documenting the sources and quantity of all inputs and the quantity and end destination of all the outputs. In a circular economy, all the inputs should be reusable as a resource (or input) in other systems. Therefore, 100% of the output from each building must be reusable / recyclable.

Nevertheless, the conclusions drawn from the assessments using the present state of the method are indicative of high circular ambitions in the designers and self-builders of the assessment cases. These intentions already take a positive step towards the integration of energy and circularity. From the assessments, it is seen that energy aspects and measures are easily implemented, due to the vast knowledge available on the subject and multiple stringent restrictions imposed by the EU. The use of materials in a circular manner have multiple factors to consider (such as assembly hierarchy, functional separation, demountable connections etc.), of which some have been implemented in the cases. Extensive information is not known on the construction methodology of these buildings, so the circular ambitions cannot be aptly graded. However, as mentioned, the intentions are in place, and it is assumed that with the availability of standardized implementable measures, the transition from linear to circular can be improved.

Sub-research question:
7. How can the integrated assessment method be improved?

The integrated assessment method has been developed and improved through an iterative process. The improvements were driven by the following:
1. Defining a strict boundary condition for the indicators

2.Defining the parameters of each indicator that is considered circular and not. For example, downcycling of materials is not considered circular in this research although it prolongs the use of the material. This is because within the set definition of a circular building, high quality reuse of a material is not facilitated by downcycling.

As mentioned, through an iterative approach of defining and constricting parameters the assessment method has been developed. The process started by initially considering only the circularity of energy installations, and then developing it to consider also the building circularity but separating them into two frameworks. When these flows were combined into one framework more refinement was done in terms of what flow comes from outside the building site, what remains within and what leaves the building site. The nature of these flows were then developed into resources, outputs and waste. Further the method was improved by including cascades within the site that lend to the circularity of the building. Developing these flows lead to an improved assessment method which is better apt for a circularity assessment. Due to lack of extensive data, the results of the assessments cannot be regarded as a complete outlook on the case buildings. In addition, as the scope of the method is restricted to materials and energy, and does not for instance include the lifecycle assessment of the building, water consumption pattern, health, biodiversity or human culture enhanced by the building, a complete circular assessment cannot be conducted with the present state of the method.

10.0 REFLECTION

10.1 GRADUATION PROCESS

With the EU setting multiple stringent goals for the energy performance of buildings, it can be said that we are already on the path towards creating an energy efficient built environment with reduced demands and emissions. Simultaneously (although not as fast paced), the EU also aims at increasing circularity in the built environment by proposing to reduce the use of primary raw materials and greenhouse gases. It is unknown if these goals intersect, and if they do, then where, and how much?
The aim of my research is to address this gap in information, as best as possible in the proposed time-line, and to facilitate this movement towards a sustainable building stock. Therefore, placing this research within the graduation studio is and was quite straightforward. The two main themes – energy and circularity, align with the building technology graduation studio themes.
Delving into the methodology of the research, there was a path chalked out from the start, which was clearly developed during P2. As this research does not have much established precedents to follow, the significance of the literature research cannot be undermined. Especially with respect to circularity, since it is a theme undergoing development and extensive research by multiple organizations currently, the literature research was very important to define a system boundary on which the research can be based.
An important and possibly crucial part of this research, one that was set to define the trajectory of the research process and outcome, was practical data collected from case studies. This research is heavily grounded in reality, as it takes actual data from newly built buildings, and therefore attaining qualitative data was very important. The collection of data is through a questionnaire that was distributed to self-builders in the case study area through a representative of a living lab in the area. This was possibly the most daunting part of the research until P3. Designing an extensive yet convenient (for respondents) questionnaire was a tedious task, however I'd like to believe the outcome was good. The design and distribution of the questionnaire is perhaps the less difficult phase, as I realized having the patience to wait for the arrival of responses was far more difficult. Even with the support of an extremely cooperative person at the living lab, the responses were slow, and when looked at from the perspective of a time bound graduation research, every day counts. It was a learning lesson to accept that the respondents cannot be expected to follow my research time plan. The finally collected data on the case study area has been assessed as best as possible, however more qualitative data would have refined the research further.

The focus after P3 (and also slightly before) was shifted to creating a framework that can be used to assess new buildings in an integrated manner so that when the right data is plugged in, the extent to which buildings are 'circular' can be determined, further leading to the possibility of improving this extent. I believe this turn of focus which became the core of my research provides a useful base upon which further research can be based in order to guide the built environment to a sustainable future. Therefore, looking back I believe this research would have been developed better and more detailed had this shift of focus had come sooner.

A facet of the research methodology that was left ambiguous and open from the start is the design task. As mentioned already, since the research is based on practical data, I wanted to ensure that the design task follows the analysis of the data and was not predefined. This posed some difficulties in the analysis phase, as it was difficult to define the extent to which each aspect in the analysis needed to be studied, and I often found myself studying extensively about the technicality of energy installations, in case I decide to redesign it. However, as the research developed the design phase grew less important in comparison to the assessment framework, as an outcome of the lack of sufficient and qualitative data on the case study buildings. If this were not the case, it would have been interesting to be able to partially redesign a building based on the conducted literature review to realistically show how design can impact the operation and demolition of a building in a positive way. Nevertheless, the design guidelines formulated in this research also provide an insight into how design decisions can impact the overall circularity of a building.

10.2 SOCIETAL IMPACT

An interesting aspect of this research is its practical applicability. Since the input is realistic and based on newly built buildings with high ambitions related to energy performance and circularity, the output will be practically applicable measures that can be incorporated to improve the design of buildings, and gear it towards a more sustainable future. While this was a conscious effort, it was also a by product of the nature of this research.

It is important to note that there is a system boundary taken in the assessment framework and the assessments of the buildings. It would be fruitful, in terms of both energy and material resources to consider a larger boundary condition, including the sources of resources as well so that more conscious decisions can be made by designers and self-builders.

Through the distributed questionnaire interesting data was gathered on the studied novel development area, and it would be useful for other self-builders of the area to have access to this information so that future buildings can be designed better using these buildings as reference points. Hopefully this is made possible through this graduation report.

To conclude, while this research depicts the current state of certain flows in existing buildings, providing possibilities for improvements that can be made easily and immediately, more complex flows are also involved in a building (within the site and outside) which directly affect the circularity (both energy and material circularity) of a building. By including these flows in the assessment during the design phase, the buildings can be further improved to create a positive impact, rather than merely reducing the negative impact as suggested in the Cradle to Cradle framework.

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1 2 . 0 A P P E N D I X

12.1 APPENDIX A

12.1.1 PRIMARY ENERGY FACTORS:

Energy Type	Primary factor (Delivered energy)
Electricity	2,56
Natural gas	1,0
Fuel oil	1,0
Wood, Biomass	1,0
External heat for heat or hot water	1,0
External cooling supply	0,833
On the private plot generated heat	
On the private plot generated cold	

Table 29.0 : Primary energy factors for delivered energy according to NEN 7120 (Instituut, Afdeling, & En, 1950)

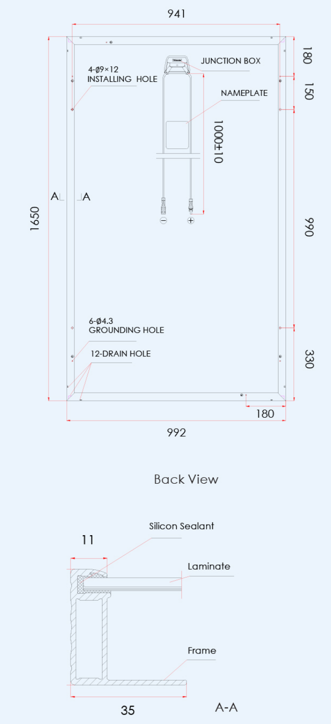
12.1.2 SOLAR PANEL :

Typical PV panel taken for demonstrating calculation of assessment framework (Section 4.2.7): (Trina Solar, 2015)

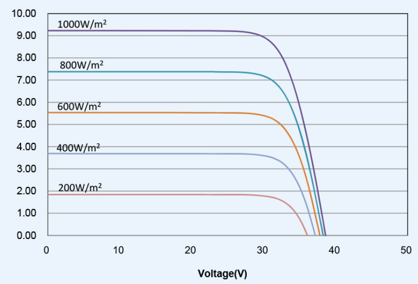
THE Honey MODULE

PRODUCTS	POWER RANGE
TSM-DC05A.08	270-275W
TSM-DC05A.05	265-275W

DIMENSIONS OF PV MODULE unit:mm



I-V CURVES OF PV MODULE(270W)



CERTIFICATION

ELECTRICAL DATA (STC)

Peak Power Watts-P_{MAX} (Wp)	265	270	275
Power Output Tolerance-P_{MAX} (W)		0 ~ +5	
Maximum Power Voltage-V_{MPP} (V)	30.7	30.8	31.2
Maximum Power Current-I_{MPP} (A)	8.63	8.77	8.82
Open Circuit Voltage-V_{OC} (V)	38.5	38.6	38.7
Short Circuit Current-I_{SC} (A)	9.10	9.23	9.26
Module Efficiency η_m (%)	16.2	16.5	16.8

STC: Irradiance 1000 W/m², Cell Temperature 25°C, Air Mass AM1.5 according to EN 60904-3.

ELECTRICAL DATA (NOCT)

Maximum Power-P_{MAX} (Wp)	197	201	205
Maximum Power Voltage-V_{MPP} (V)	28.6	28.8	29.1
Maximum Power Current-I_{MPP} (A)	6.88	6.99	7.03
Open Circuit Voltage-V_{OC} (V)	35.7	35.9	35.9
Short Circuit Current-I_{SC} (A)	7.35	7.45	7.48

NOCT: Irradiance at 800 W/m², Ambient Temperature 20°C, Wind Speed 1 m/s.

MECHANICAL DATA

Solar cells	Monocrystalline 156 × 156 mm (6 inches)
Cell orientation	60 cells (6 × 10)
Module dimensions	1650 × 992 × 35 mm
Weight	18.6 kg
Glass	3.2 mm,High Transmission, AR Coated Tempered Glass
Backsheet	White(DC05A.08); Black(DC05A.05)
Frame	Black anodized aluminium alloy
J-Box	IP 65 or IP 67 rated
Cables	Photovoltaic Technology cable 4.0 mm², 1000 mm
Connector	MC4 Compatible

TEMPERATURE RATINGS

Nominal Operating Cell Temperature (NOCT)	44°C(± 2°C)
Temperature Coefficient of P_{MAX}	- 0.40%/°C
Temperature Coefficient of V_{OC}	- 0.31%/°C
Temperature Coefficient of I_{SC}	0.05%/°C

MAXIMUM RATINGS

Operational Temperature	-40~+85°C
Maximum System Voltage	1000V DC (IEC)
Max Series Fuse Rating	15A

WARRANTY

10 year Product Workmanship Warranty

25 year Linear Power Warranty

(Please refer to product warranty for details)

PACKAGING CONFIGURATION

Modules per box: 30 pieces

Modules per 40' container: 840 pieces

TSM_EN_2015_B

CAUTION: READ SAFETY AND INSTALLATION INSTRUCTIONS BEFORE USING THE PRODUCT.

Trinasolar Smart Energy Together

MPG calculation of 25m2 of PV panel, done for demonstrating calculation of assessment framework (Sectin 4.2.7):

Rapportage Freetool MRPI Milieuprestatie Gebouw

In deze rapportage zijn de resultaten en de invoer opgenomen van de milieuprestatieberekening gebouw van Rooftop PV panel. De resultaten zijn verdeeld naar de verplichte milieuprestatieberekening voor het bouwbesluit op basis van afdeling 5.2 en naar de MPG score. Tot slot is een verantwoording voor de berekening opgenomen.

Algemene gegevens

Naam project:	Rooftop PV panel
Organisatie:	TU Delft
Gebruiksfunctie:	Woongebouw
Bvo:	200 m2
Levensduur:	75 jaar
Datum rapportage:	09-04-2019

Resultaat bouwbesluit

In bijlage I is een overzicht opgenomen van de geselecteerde producten inclusief hoeveelheden en eventuele dimensies van het product. In de onderstaande tabel zijn de relevante resultaten opgenomen.

Milieu-impact	berekende waarde	eenheid
Uitputting abiotische grondstoffen (excl. fossiel)	0	kg Sb eq./ m2 BVO*jaar
Uitputting fossiele energiedragers	0,014	kg Sb eq./ m2 BVO*jaar
Klimaatverandering (100 jaar)	2,06	kg CO2 eq./ m2 BVO*jaar

De berekende resultaten zijn direct gekoppeld aan de in bijlage I opgenomen producten, een afwijkende materialisatie of productkeuze heeft invloed op de berekening. Indien in het verdere ontwerp- en bouwproces andere materiaalkeuzes worden gemaakt dient de milieuprestatie opnieuw berekend te worden.

Resultaat MPG-score

In bijlage I is een overzicht opgenomen van de geselecteerde producten inclusief hoeveelheden en eventuele dimensies van het product. De MPG-score van Rooftop PV panel is 0,27 € / m2 BVO. In de onderstaande tabel is dit resultaat weergegeven naar de verschillende bouwdelen.

Bouwdeel	Resultaat
Fundering	0%
Vloeren	0%
Draagconstructie	0%
Gevels	0%
Daken	0%
Installaties	100%
Inbouw	0%

Rapportage Freetool MRPI Milieuprestatie Gebouw

Bijlage I, invoer berekening

- ongetoetst
- getoetst

Fundering

Vloeren

Draagconstructie

Gevels

Daken

Installaties

Elektrische installatie

Elektriciteitsopwekkingsystemen	PV,mono-Si; hellend dak; incl. inverter+kabels	25 m2

Inbouw

12.1.3 SOLAR COLLECTOR :

Details of typical evaucated solar collecotr taken as reference for case study assessments:

SPECIFICATION

Series		CPC1506
No. of Evacuated Tubes		6
η (Aperture), DIN 4757-4 or EN 12975	%	64.2
c1 with wind, in relation to aperture	W/(m²k)	0.89
c2 with wind, in relation to aperture	W/(m²k²)	0.001
Yield forecast	kWh/m²a	651
(location Würzburg, Germany, reference area 3m²)		
Yield forecast	kWh/m²a	589
(location Würzburg, Germany, reference area 5m²)		
Grid dimensions (length x height x depth)	m	0.70 x 1.64 x 0.1
Gross surface area	m²	1.15
Aperture area	m²	1.0
Collector contents	l	0.8
Weight	kg	19
Max. working overpressure	bar	10
Max. stagnation temperature	°C	272
Connection diameter, clamping ring	mm	15
Sensor sleeve	mm	6
Collector material		Al / Cu / glass / Silicone / PBT / EPDM / TE
Glass tube material		Borosilicate glass 3.3
Selective absorber coating material		Aluminium nitride
Glass tube (Ø ext./Ø int./wall thckn./tube lgth.)	mm	47/37/1.6/1500
Colour (aluminium frame profile, anodised)		Aluminium grey
Colour (plastic parts)		Black
Thermal shock test	ITW test	06COL513/1
Hailstone test according to DIN EN 12975-2	TÜV test	435/142448
EC type examination		Z-IS-DDK-MUC-07-08-100029919-003

12.2 APPENDIX B

Questionnaire for collection of building data from self builders in the case study development : Buiksloterham.

Inventarisatie van energie-efficiëntie en circulariteit van zelfbouw woningen in Buiksloterham

Beste bewoner, de volgende vragenlijst is bedoeld als hulp bij een onderzoek naar de energie-efficiëntie en circulariteit van nieuwe woningen in Buiksloterham. De verzamelde informatie zal worden gebruikt voor een inventaris van nieuwe technologieën die in Buiksloterham worden toegepast, met als doel richtlijnen en tips voor nieuwe bewoners te kunnen geven om Buiksloterham Circulair te maken! Alvast hartelijk dank voor het invullen van de enquete.

Opmerking: het Google-formulier verzamelt automatisch (ALLEEN) de naam en foto van het Google-accountals een bestand wordt geüpload, en u kunt er zeker van zijn dat deze informatie vertrouwelijk is en geen deel uitmaakt van het onderzoek. Bedankt voor uw begrip.

Naam

Short answer text

Email

Dit wordt vertrouwelijk behandeld en is alleen vereist in het geval van een vervolgvraag

Short answer text

Algemene informatie

Kavel nummer

Short answer text

Bouwjaar

Short answer text

Architecturale gegevens

Bruto vloeroppervlak (m²)

Ruimte van alle gebruikte ruimtes + gangen + trappen

Short answer text

Energie Prestatie Coefficient (EPC)

Energie Prestatie Coefficient (EPC) van het gebouw

Short answer text

Upload EPC-berekening / rapport

Mocht u een EPC rapport hebben en willen uploaden, dan kunnen wij daar de benodigde informatie uit halen en hoeft u verder geen vragen over energie in te vullen.

Heb je een EPC-berekening / -rapport geüpload? *

Als u het rapport hebt geüpload, worden de energievragen automatisch overgeslagen

- Ja
- Nee

Bouw eigenschappen

Is uw woning (gebouw), voor zover u weet, beter geïsoleerd dan volgens de normen uit het Bouwbesluit? *

Bouwbesluit standard: Vloer - Rc: 3,5, Dak: - Rc: 6,0, Gevel - Rc: 4,5 [m2K/W]

- Ja
- Nee
- Onbekend

Isolatie: Indien bekend, wat is de isoaltiewaarde van de vloer?

1. Rc = 3.5
2. Rc = 4.5
3. Rc >= 5.5
4. Rc >=6
5. Rc >=7
6. Rc>= 8
7. Onbekend

Isolatie: Indien bekend, wat is de isoaltiewaarde van de gevel?

1. Rc = 3.5
2. Rc = 4.5
3. Rc >= 5.5
4. Rc >=6
5. Rc >=7
6. Rc>= 8

Isolatie: Indien bekend, wat is de isoaltiewaarde van de dak?

1. Rc = 3.5
2. Rc = 4.5
3. Rc >= 5.5
4. Rc >=6
5. Rc >=7
6. Rc>= 8
7. Onbekend

Beglazing: welk soort beglazing is in de woning gebruikt en wat is de Uvalue van deze beglazing?

1. Double glazing with U>=1.2
2. Double glazing with U >=1.1
3. Double glazing with U <=1.0
4. Double glazing with U <= 0.7
5. Onbekend

Warm water voor huishoudelijk gebruik

Type systeem

- Zonnecollector
- Stadsverwarming
- Warmtepomp
- Other...

Heeft het huis een douche-warmteterugwinningssysteem?

- ◯ Ja
- ◯ Nee

Ventilatiesysteem

De volgende vragen gaan over het ventilatiesysteem van de woning

Type ventilatiesysteem

- ◯ Natuurlijke toevoer & mechanische afvoer (Type C)
- ◯ Mechanische aanvoer en afvoer - centraal (Type Dc)
- ◯ Mechanische aanvoer & afvoer - gedecentraliseerd(Type Dd)
- ◯ Gecombineerd systeem (Type E)

Is er een warmteterugwinningssysteem toegepast in de ventilatie-unit?

- ◯ Ja
- ◯ Nee
- ◯ Niet van toepassing

Verwarming

Hoe worden de kamers verwarmd?

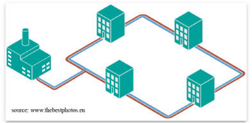
- ☐ Conventionele radiator

- ☐ Lage temperatuur radiator

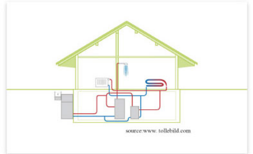
- ☐ Oppervlakteverwarming (vloeren / muren)

Wat is de warmtetoevoerbron voor ruimteverwarming?

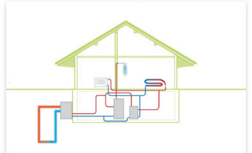
- ☐ Stadsverwarming



- ☐ Warmtepomp met luchtbron



- ☐ Warmtepomp met grondbron



- ☐ Hout pellets

- ☐ Other...

Koeling

Heeft u in uw woning de mogelijkheid tot actieve koeling? (d.w.z. koeling door middel van een airco, vloerkoeling of ander actief apparaat).

- ◯ Ja
- ◯ Nee
- ◯ Onbekend

Indien bekend, geef alstublieft aan (meerdere antwoorden mogelijk)

- ☐ Split unit airco

- ☐ Warmtepomp aangesloten op vloerkoeling

- ☐ Other...

Anders

Welke andere duurzame maatregelen zijn toegepast in de woning? (meerdere antwoorden mogelijk)

- [ ] Collectie van regenwater voor gebruik binnenshuis (bijv. toiletspoeling)
- [ ] Collective van regenwaater voor gebruik buitenshuis (bijv. tuin)
- [ ] Lokale zuivering en gebruik van grijswater
- [ ] Biogas reactor
- [ ] Other...

Zijn er op het gebouw zonnepanelen (PV) geïnstalleerd? *

- ( ) Ja
- ( ) Nee
- ( ) Onbekend

Zonnepanelen (PV)

Indien bekend: Wat is het totale oppervlak (m²) aan zonnepanelen (PV) dat op de woning is geïnstalleerd?

Short answer text

Indien bekend: Wat is het geïnstalleerde vermogen in wattpiek op het pand?

Short answer text

Gebruikerstevredenheid

Hoe tevreden bent u met de energieprestaties van uw huis?

	1	2	3	4	5	6	7	8	9	10	
Zeer ontevreden	○	○	○	○	○	○	○	○	○	○	Zeer tevreden

Hoe tevreden bent u met het thermisch comfort van uw huis?

	1	2	3	4	5	6	7	8	9	10	
Zeer ontevreden	○	○	○	○	○	○	○	○	○	○	Zeer tevreden

Andere aanvullende informatie:

Long answer text

Aanvullende informatie

Indien u uw jaarlijkse energiegebruik wee ten dit wilt delen, wilt u dan onderstaande vragen invullen:

Wat is uw maandelijkse energierekening (bij benadering)?

Short answer text

Indien bekend: Jaarlijkse elektriciteitsgebruik [.....kWh/jaar]

Short answer text

Indien bekend: Bij externe warmtelevering/standsverwarming: jaarlijkse warmtegebruik [.....GJ/jaar]

Short answer text

Bouwaanvraag tekening

Upload Bouwaanvraag tekening

Mocht u een bouwaanvraag tekening hebben en willen uploaden, dan kunnen wij daar de benodigde informatie uit halen en hoeft u verder geen vragen over materialen in te vullen.

Heb je een Bouwaanvraag tekening geüpload? *

Als u het tekening hebt geüpload, worden de materiaalvragen automatisch overgeslagen

- ( ) Ja
- ( ) Nee

Materiële keuze

Wordt een van de volgende aspecten in aanmerking genomen bij het kiezen van de materialen voor het huis? (meerdere antwoorden mogelijk):

	Kosten	Gezondheid	Circulariteit	Energiezuinigheid	Milieubelasting ma...	Geen van bovensta...	Niet van toepassing
Fundering	☐	☐	☐	☐	☐	☐	☐
Begane grond	☐	☐	☐	☐	☐	☐	☐
Bovenste verdiepi	☐	☐	☐	☐	☐	☐	☐
Dragende structuur	☐	☐	☐	☐	☐	☐	☐
Gevel	☐	☐	☐	☐	☐	☐	☐

Andere aanvullende informatie:

Long answer text

Materialen - Fundering

Zijn er hernieuwbare materialen / componenten / elementen gebruikt bij de fundering van het huis? *

Opmerking: geef alsjeblieft aan of ja als: het materiaal zelf is biologisch afbreekbaar en hernieuwbaar, of als het onderdeel kan worden gerecycled tot nieuwe componenten.

- ○ Ja
- ○ Nee
- ○ Onbekend

Fundering

Indien bekend: Noem het volgende

Constructiemateriaal + Isolatie + Andere extra laag + Chemische behandeling

* chemisch behandelingsvoorbeeld: termietbestendig

Long answer text

Is bij de keuze van de materialen special rekening gehouden met een van de onderstaande aspecten (meerdere antwoorden mogelijk):

- ☐ Kosten
- ☐ Gezondheid
- ☐ Circulariteit
- ☐ Energiezuinigheid
- ☐ Milieubelasting materialen
- ☐ Geen van bovenstaande
- ☐ Other...

Materialen - Begane grond

Zijn er hernieuwbare materialen / componenten / elementen gebruikt bij de begane grond van het huis? *

Opmerking: geef alsjeblieft aan of ja als: het materiaal zelf is biologisch afbreekbaar en hernieuwbaar, of als het onderdeel kan worden gerecycled tot nieuwe componenten.

- ○ Ja
- ○ Nee
- ○ Onbekend

Begane grond

Indien bekend: Noem het volgende

Constructiemateriaal + Isolatie + Andere extra laag + Chemische behandeling

* chemisch behandelingsvoorbeeld: Epoxy-coating

Long answer text

Ook indien bekend:

Productnaam

Short answer text

Is bij de keuze van de materialen special rekening gehouden met een van de onderstaande aspecten (meerdere antwoorden mogelijk):

- ☐ Kosten
- ☐ Gezondheid
- ☐ Circulariteit
- ☐ Energiezuinigheid
- ☐ Milieubelasting materialen
- ☐ Geen van bovenstaande
- ☐ Other...

Materialen -Bovenste verdiepi

Zijn er hernieuwbare materialen / componenten / elementen gebruikt bij de bovenste verdiepi van het huis? *

Opmerking: geef alsjeblieft aan of ja als: het materiaal zelf is biologisch afbreekbaar en hernieuwbaar, of als het onderdeel kan worden gerecycled tot nieuwe componenten.

- ○ Ja
- ○ Nee
- ○ Onbekend

Indien bekend: Noem het volgende

Description (optional)

Constructiemateriaal + Isolatie + Andere extra laag + Chemische behandeling

* chemisch behandelingsvoorbeeld: Epoxy-coating

Long answer text

Productnaam

Short answer text

Is bij de keuze van de materialen special rekening gehouden met een van de onderstaande aspecten (meerdere antwoorden mogelijk):

- [ ] Kosten
- [ ] Gezondheid
- [ ] Circulariteit
- [ ] Energiezuinigheid
- [ ] Milieubelasting materialen
- [ ] Geen van bovenstaande
- [ ] Other...

Materialen - Dragende structuur

Indien bekend: Noem het volgende

Constructiemateriaal

Long answer text

Ook indien bekend:

Productnaam

Short answer text

Is bij de keuze van de materialen special rekening gehouden met een van de onderstaande aspecten (meerdere antwoorden mogelijk):

- [ ] Kosten
- [ ] Gezondheid
- [ ] Circulariteit
- [ ] Energiezuinigheid
- [ ] Milieubelasting materialen
- [ ] Geen van bovenstaande
- [ ] Other...

Materialen - Gevel

Zijn er hernieuwbare materialen / componenten / elementen gebruikt bij de gevel van het huis? *

Opmerking: geef alsjeblieft aan of ja als: het materiaal zelf is biologisch afbreekbaar en hernieuwbaar, of als het onderdeel kan worden gerecycled tot nieuwe componenten.

- ○ Ja
- ○ Nee
- ○ Onbekend

Gevel

Indien bekend: Noem het volgende

Isolatiemateriaal + Andere extra laag + Chemische behandeling

* chemisch behandelingsvoorbeeld: glascoating

Long answer text

Ook indien bekend:
Productnaam

Short answer text

Is bij de keuze van de materialen special rekening gehouden met een van de onderstaande aspecten (meerdere antwoorden mogelijk):

- [ ] Kosten
- [ ] Gezondheid
- [ ] Circulariteit
- [ ] Milieubelasting materialen
- [ ] Geen van bovenstaande
- [ ] Other...

Materialen - Binnenmuren

Zijn er hernieuwbare materialen / componenten / elementen gebruikt bij de binnenmuren van het huis? *

Opmerking: geef alsjeblieft aan of ja als: het materiaal zelf is biologisch afbreekbaar en hernieuwbaar, of als het onderdeel kan worden gerecycled tot nieuwe componenten.

- ○ Ja
- ○ Nee
- ○ Onbekend

Is bij de keuze van de materialen special rekening gehouden met een van de onderstaande aspecten (meerdere antwoorden mogelijk):

☐ Kosten

☐ Gezondheid

☐ Circulariteit

☐ Energiezuinigheid

☐ Milieubelasting materialen

☐ Geen van bovenstaande

☐ Other...

Materialen - Dakopbouw

Zijn er hernieuwbare materialen / componenten / elementen gebruikt bij de dakopbouw van het huis? *

Opmerking: geef alsjeblieft aan of ja als: het materiaal zelf is biologisch afbreekbaar en hernieuwbaar, of als het onderdeel kan worden gerecycled tot nieuwe componenten.

◯ Ja

◯ Nee

◯ Onbekend

Dakopbouw

Ook indien bekend:

Productnaam

Short answer text

Is bij de keuze van de materialen special rekening gehouden met een van de onderstaande aspecten (meerdere antwoorden mogelijk):

☐ Kosten

☐ Gezondheid

☐ Circulariteit

☐ Energiezuinigheid

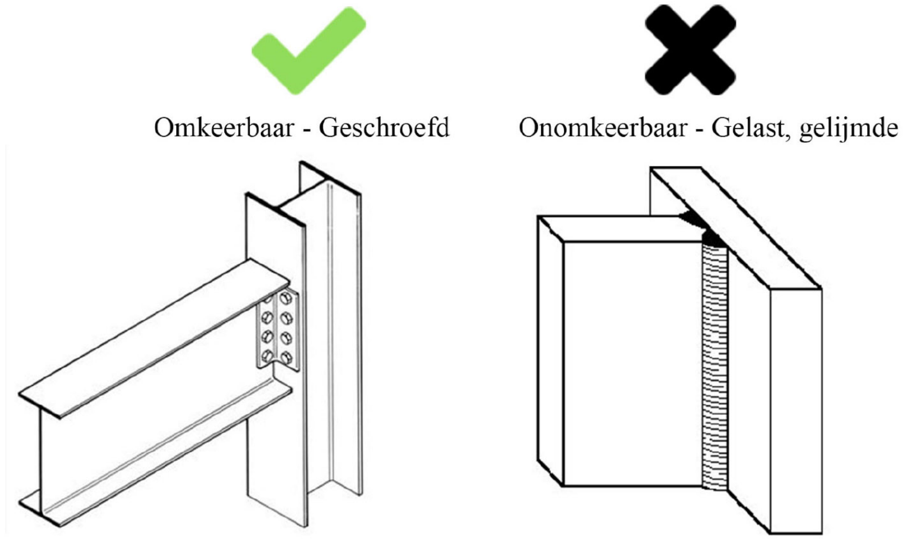
☐ Milieubelasting materialen

☐ Geen van bovenstaande

☐ Other...

Verbindingen

Voor zover u weet, zijn omkeerbaar verbindingen (bout- en moerverbinding of geschroefd enz.) Gebruikt voor het volgende:



	Ja	Nee	Onbekend
Begane grond	☐	☐	☐
Bovenste verdieping	☐	☐	☐
Gevel	☐	☐	☐
Binnenmuren	☐	☐	☐
Dakopbouw	☐	☐	☐

Afvalproductie

Indien bekend: In welke categorieën is het bouwafval gescheiden? (meerdere antwoorden mogelijk)

☐ Houtafval - voorbeeld: hout, multiplex

☐ Metaalresten - voorbeeld: HVAC-kanaalsecties, aluminiumplaten

☐ Staalschroot - voorbeeld: wapeningsstaven

☐ Beton - voorbeeld: betonschilfers, betonblokken

☐ Bakstenen

☐ Gipsplaten / scheidingsbordafval

☐ Tegels en / of keramiek

☐ Glas

☐ Kunststoffen - voorbeeld: buizen

☐ Other...

12.3 APPENDIX C : ASSESSMENT CASE 01

12.3.1 QUESTIONNAIRE RESPONSE :

TU Delft Delft University of Technology

Inventarisatie van energie-efficiëntie en circulariteit van zelfbouw woningen in Buiksloterham

Beste bewoner, de volgende vragenlijst is bedoeld als hulp bij een onderzoek naar de energie-efficiëntie en circulariteit van nieuwe woningen in Buiksloterham. De verzamelde informatie zal worden gebruikt voor een inventaris van nieuwe technologieën die in Buiksloterham worden toegepast, met als doel richtlijnen en tips voor nieuwe bewoners te kunnen geven om Buiksloterham Circulair te maken! Alvast hartelijk dank voor het invullen van de enquete.

Algemene informatie

Bouwjaar

2016

Aantal bewoners in de woning

6

Architecturale gegevens

Bruto vloeroppervlak (m^2)
Ruimte van alle gebruikte ruimtes + gangen + trappen

218

Energie Prestatie Coefficient (EPC)

Energie Prestatie Coefficient (EPC) van het gebouw

0,6

Upload EPC-berekening / rapport
Mocht u een EPC rapport hebben en willen uploaden, dan kunnen wij daar de benodigde informatie uit halen en hoeft u verder geen vragen over energie in te vullen.

PDF definitief rapport B...

Heb je een EPC-berekening / -rapport geüpload? *
Als u het rapport hebt geüpload, worden de energievragen automatisch overgeslagen

- (●) Ja
- ( ) Nee

Gebruikerstevredenheid

Hoe tevreden bent u met de energieprestaties van uw huis?

	1	2	3	4	5	6	7	8	9	10	
Zeer ontevreden	○	○	○	○	○	●	○	○	○	○	Zeer tevreden

Hoe tevreden bent u met het thermisch comfort van uw huis?

	1	2	3	4	5	6	7	8	9	10	
Zeer ontevreden	○	○	○	○	○	◉	○	○	○	○	Zeer tevreden

Andere aanvullende informatie:

we hebben nog niet de definitieve verwarming/tapwater installatie geïnstalleerd. Maar alle passieve aspecten: veel natuurlijk licht en zonne-energie, erg goed binnenklimaat en binnenluchtkwaliteit, zeer goede thermische isolatie, geen tochtverschijnselen door dubbele gevel, ect werkt uitstekend,

Materialen - Begane grond

Zijn er hernieuwbare materialen / componenten / elementen gebruikt bij de begane grond van het huis? *

Opmerking: geef alsjeblieft aan of ja als: het materiaal zelf is biologisch afbreekbaar en hernieuwbaar, of als het onderdeel kan worden gerecycled tot nieuwe componenten.

- ◉ Ja
- ○ Nee
- ○ Onbekend

Materialen -Bovenste verdiepi

Zijn er hernieuwbare materialen / componenten / elementen gebruikt bij de bovenste verdiepi van het huis? *

Opmerking: geef alsjeblieft aan of ja als: het materiaal zelf is biologisch afbreekbaar en hernieuwbaar, of als het onderdeel kan worden gerecycled tot nieuwe componenten.

- ◉ Ja
- ○ Nee
- ○ Onbekend

Materialen - Dragende structuur

Zijn er hernieuwbare materialen / componenten / elementen gebruikt bij de dragende structuur van het huis? *

Opmerking: geef alsjeblieft aan of ja als: het materiaal zelf is biologisch afbreekbaar en hernieuwbaar, of als het onderdeel kan worden gerecycled tot nieuwe componenten.

- ◉ Ja
- ○ Nee
- ○ Onbekend

Materialen - Dakopbouw

Zijn er hernieuwbare materialen / componenten / elementen gebruikt bij de dakopbouw van het huis? *

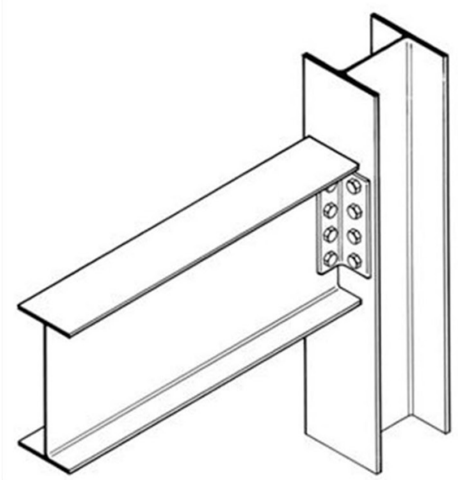
Opmerking: geef alsjeblieft aan of ja als: het materiaal zelf is biologisch afbreekbaar en hernieuwbaar, of als het onderdeel kan worden gerecycled tot nieuwe componenten.

- ◉ Ja
- ○ Nee
- ○ Onbekend

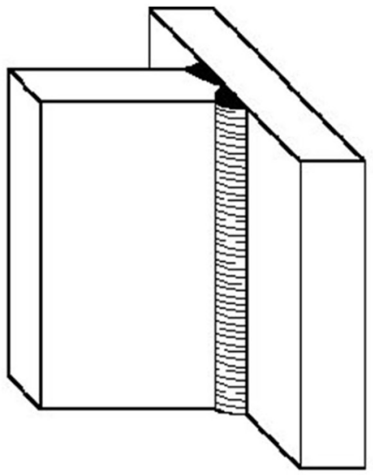
Verbindingen

Voor zover u weet, zijn omkeerbaar verbindingen (bout- en moerverbinding of geschroefd enz.) Gebruikt voor het volgende:

Omkeerbaar - Geschroefd



Onomkeerbaar - Gelast, gelijmde



	Ja	Nee	Onbekend
Begane grond	☐	☑	☐
Bovenste verdieping	☐	☑	☐
Gevel	☐	☑	☐
Binnenmuren	☐	☑	☐
Dakopbouw	☐	☑	☐

12.3.2 EPC CALCULATION REPORT :

The energy performance calculations in this section was commissioned by Thomas Dill, in accordance to NEN 7120.

Energieprestatie

De energieprestatiecoëfficiënt is berekend volgens NEN 7120. Binnen het kader van de NEN7120 worden de bedrijfsruimten op de begane grond beschouwd als woonfunctie (het vloeroppervlak van deze ruimten bedraagt minder dan 50 m2 én minder dan 50% van het woonoppervlak). De 'gebouwgebonden buitenruimte' is gemodelleerd als Aangrenzende Onverwarmde Serre (AOS). Voor wat betreft de buurwoning is de werkelijke geometrie van deze woning berekend. Waar de woning aan de buurwoning grenst, vindt geen warmte-uitwisseling plaats. Via zijgevelvlakken die aan de buitenlucht grenzen, wordt uiteraard wel warmte-uitwisseling berekend.

Uitgangspunten
De volgende uitgangspunten zijn gehanteerd:
- Isolatie begane-grondvloer (VBI-kanaalplaat met 192 mm EPS): Rc=5,0 m2K/W.
- Isolatie buitengeve: Rc=5,2 m2K/W.
- Isolatie plat dak: Rc=4,7 m2K/W.
- Isolatie overstekken dak (25 mm vacuumisolatie): Rc=4,0 m2K/W.
- Isolatie overstekken vloer (80 mm PIR): Rc=3,9 m2K/W.
- Houten kozijnen met HR++ beglazing (uitgangspunt Uglas=1,0 m2K/W en aluminium afstandhouders); Uraam=1,42 W/m2K. In verband met de serrepui (20% reductie), bedraagt de ZTA 45%.
- De aangrenzende onverwarmde serre heeft een buitenschil van enkelglas in aluminium kozijnen (Uw=5,8 W/m2K).
- Er wordt bedienbare buitenzonwering toegepast voor de zuidwestgevel.
- PV-panelen en vacuumbuiscollectoren zijn qua zonwering gemodelleerd als 'zonwerend glas' met ZTA=25%.
- De lineaire koudebruggen zijn uitgebreid berekend.
- Ruimteverwarming en warm-tapwater worden geleverd door vacuumbuiscollectoren (57 m2 collectoren in gevel- en op dakvlak met 25m3 opslagtank) aangevuld door houtgestookte kachels (één per wooneenheid). Warmteafgifte gebeurt d.m.v. vloerverwarming.
- Omdat binnen de NEN7120 het niet mogelijk is om een grote bijdrage van thermische zonne-energie met seizoensopslag juist te berekeken, is op basis van gelijkwaardigheid gebruik gemaakt van de berekening door leverancier F-save.
- Er wordt douchewater-warmteterugwinning toegepast.
- Ventilatie: gebalanceerde ventilatie met HR-warmteterugwinning en bypass (één per wooneenheid).
- Op het dakvlak wordt 25,6 m2 PV panelen met een piekvermogen van 120 Wp/m2 geplaatst.

De berekening van de EPC inclusief het op basis van gelijkwaardigheid berekende effect van de zonnecollectoren, seizoensopslag en biomassaverwarming is weergegeven in bijlage 3. De onderliggende EPC berekening is weergegeven in bijlage 4. De berekening van de bijdrage van de zonnecollectoren en seizoensopslag is weergegeven in bijlage 5.

Resultaat en conclusie
Het resultaat van de berekening is onderstaand weergegeven.

	EPC	EPC-eis	conclusie
Woning (2 wooneenheden) BSH05 R	0,21	0,60	voldoet

De EPC van de woning met 2 wooneenheden voldoet aan de eis. In verband met de toepassing van houtkachels (biomassaverwarming) is conform de gelijkwaardigheidsverklaring nog een extra controle vereist: bij een fictief rendement van 1,0 dient de EPC kleiner dan 1,333 maal de eis te zijn. Resultaat: Bij fictief rendement 1,0 bedraagt de EPC 0,27 en dat is inderdaad lager dan 1,333*0,6=0,80.

Ventilatie

De ventilatie gebeurt door middel van mechanische toe- en afvoer. De berekening is weergegeven in bijlage 1.

- Per ruimte dienen ventilatie-inblaas en -afzuigroosters te worden aangebracht en ingeregeld volgens de in bijlage 1 aangegeven waarden.

Daglichttoetreding

De daglichttoetreding is berekend volgens NEN 2057:2011 en getoetst aan de eisen in het bouwbesluit. De berekening is weergegeven in bijlage 2. De daglichtbelemmering als gevolg van de serrepui is ingeschat. In situaties waarin de serrepui dicht voor de betreffende daglichtopening langs loopt, is een belemmeringsfactor Cu=0,7 aangehouden. In situaties waarin de serrepui verder van de daglichtopening af staat, is een belemmeringsfactor Cu=0,4 aangehouden.

- In alle verblijfsruimten en verblijfsgebieden is voldoende daglichttoetreding.

Bijlage 3 Berekening gelijkwaardige energiezuinigheid

Resultaten gelijkwaardige energiezuinigheid
primaire-energiefactor=0 conform GW-verklaring TNO

Jaarlijkse hoeveelheid primaire energie voor de energiefunctie		
verwarming		0.000 MJ
warmtapwater		0.000 MJ
koeling		0.000 MJ
zomercomfort		34.539 MJ
ventilatoren		4.870 MJ
verlichting		8.437 MJ
geexporteerde warmte/koude		0.000 MJ
geexporteerde elektriciteit		0.000 MJ
op eigen perceel opgew. elektr. - installaties		-12.036 MJ
op eigen perceel opgew. elektr. - huishoudelijk		-11.030 MJ
elektriciteitsverbruik thermische zonne-installatie		0.392 MJ
Energieprestatie		
karakteristiek energiegebruik		25.172 MJ
toelaatbaar karakteristiek energiegebruik		74.015 MJ
energieprestatiecoefficient	EPC	0,204

Resultaten gelijkwaardige energiezuinigheid (getrapte eis)
primaire-energiefactor=1 check getrapte eis conform GW-verklaring TNO

Jaarlijkse hoeveelheid primaire energie voor de energiefunctie			
verwarming		6.053 MJ	80% gedekt door zonnecollectoren
warmtapwater		1.910 MJ	90% gedekt door zonnecollectoren
koeling		0.000 MJ	
zomercomfort		34.539 MJ	
ventilatoren		4.870 MJ	
verlichting		8.437 MJ	
geexporteerde warmte/koude		0.000 MJ	
geexporteerde elektriciteit		0.000 MJ	
op eigen perceel opgew. elektr. - installaties		-12.036 MJ	
op eigen perceel opgew. elektr. - huishoudelijk		-11.030 MJ	
elektriciteitsverbruik thermische zonne-installatie		0.392 MJ	
Energieprestatie			
karakteristiek energiegebruik		33.135 MJ	
toelaatbaar karakteristiek energiegebruik		74.015 MJ	
energieprestatiecoefficient	EPC	0,269	

Uniec 2.0

1339 BSH05 R - Kashuis - zonder collectoren bouwaanvraag	0,60

Algemene gegevens

projectomschrijving	*Kashuis - zonder collectoren*
variant	*bouwaanvraag*
adres	*BSH05 R*
postcode / plaats	*Amsterdam*
bouwjaar	*2014*
categorie	*woningbouw*
aantal woningbouw-eenheden in berekening	*2*
gebruiksfunctie	*woonfunctie*
datum	*31-07-2013*
opmerkingen	

Indeling gebouw

Eigenschappen rekenzones

type rekenzone	omschrijving	interne warmtecapaciteit	A_g [m²]	aantal woningbouw-eenheden
verwarmde zone	woonfunctie	traditioneel, gemengd zwaar	183,10	2
AOS	serre	n.v.t.	207,00	0

Infiltratie

meetwaarde voor infiltratie $q_{v;10;spec}$	*nee*
lengte van het gebouw	*6,70 m*
breedte van het gebouw	*15,00 m*
hoogte van het gebouw	*15,00 m*

Eigenschappen infiltratie

rekenzone	gebouwtype	$q_{v;10;spec}$ [dm³/s per m²]
woonfunctie	grondgebonden gebouw, kop-, eind- of hoekligging, plat dak	0,59

Open verbrandingstoestellen

Het gebouw bevat geen open verbrandingstoestellen.

Bouwkundige transmissiegegevens

Transmissiegegevens rekenzone woonfunctie

constructie	A [m²]	R_c [m²K/W]	U [W/m²K]	g_{gl} [-]	$F_{ss;gl}$ [-]	zonwering	beschaduwing	toelichting

bg vloer - kruipruimte - 39,2 m²

Transmissiegegevens rekenzone woonfunctie

constructie	A [m²]	R_c [m²K/W]	U [W/m²K]	g_{gl} [-]	$F_{ss;gl}$ [-]	zonwering	beschaduwing	toelichting
bg vloer	39,20	5,00						
noordwestgevel - buitenlucht, NW - 37,1 m² - 90°								
buitengevel	37,10	5,20					minimale belem.	
serreplafonds - AOS; serre; HOR, dak - 27,2 m² - 0°								
overstek dak	27,20	3,90					minimale belem.	
serreplafond, dak 3e - AOS; serre; HOR, dak - 47,1 m² - 0°								
plat dak	47,10	4,70					minimale belem.	
serrevloer - AOS; serre; HOR, vloer - 32,1 m² - 180°								
overstek vloer	32,10	4,00					minimale belem.	
serrevloer, trap - AOS; serre; HOR, vloer - 3,8 m² - 180°								
overstek vloer	3,80	4,00					minimale belem.	
nw serregevel - AOS; serre; NW - 37,6 m² - 90°								
buitengevel	4,50	5,20					minimale belem.	
ramen en puien	33,10		1,42	0,45	1,00	nee	volledige belem.	terugliggend
zo serregevel - AOS; serre; ZO - 146,4 m² - 90°								
buitengevel	87,10	5,20					minimale belem.	
ramen en puien	12,00		1,42	0,45	1,00	nee	minimale belem.	
ramen en puien	47,30		1,42	0,45	1,00	nee	volledige belem.	terugliggend
no serregevel - AOS; serre; NO - 106,5 m² - 90°								
buitengevel	75,80	5,20					minimale belem.	
ramen en puien	3,00		1,42	0,45	1,00	nee	minimale belem.	
ramen en puien	27,70		1,42	0,45	1,00	nee	volledige belem.	terugliggend
zw serregevel - AOS; serre; ZW - 106,5 m² - 90°								
buitengevel	64,30	5,20					minimale belem.	
ramen en puien	31,20		1,42	0,45	1,00	ja	minimale belem.	
ramen en puien	11,00		1,42	0,45	1,00	ja	volledige belem.	terugliggend

Lineaire transmissiegegevens rekenzone woonfunctie							
constructie	l [m]	$\psi_{(e)}$ [W/m¹K]	ψ_{gr} [W/m¹K]	omschrijving	+25%	ε [m²/m¹]	toelichting
bg vloer - kruipruimte - 39,2 m²							
vloerrand	6,60	0,900	-0,100	perimeter	n.v.t.	0,0012	
noordwestgevel - buitenlucht, NW - 37,1 m² - 90°							
gevelhoek	9,80	0,150		13. binnensp. op gevel (uitw.)	n.v.t.		
gevelaansl buren	9,80	-0,150		14. binnensp. op gevel (inw.)	n.v.t.		

Lineaire transmissiegegevens rekenzone woonfunctie							
constructie	l [m]	$\psi_{(e)}$ [W/m¹K]	ψ_{gr} [W/m¹K]	omschrijving	+25%	ε [m²/m¹]	toelichting
serreplafonds - AOS; serre; HOR, dak - 27,2 m² - 0°							
dakrand	29,80	0,150		1. dakrand plat dak	n.v.t.		
opgaand werk	20,40	0,200		16. opgaand werk	n.v.t.		
serreplafond, dak 3e - AOS; serre; HOR, dak - 47,1 m² - 0°							
dakrand	45,00	0,150		1. dakrand plat dak	n.v.t.		
serrevloer - AOS; serre; HOR, vloer - 32,1 m² - 180°							
vloerondersteuning	34,20	0,250		17. uitkragingen	n.v.t.		
serrevloer, trap - AOS; serre; HOR, vloer - 3,8 m² - 180°							
vloerondersteuning	5,00	0,250		17. uitkragingen	n.v.t.		
nw serregevel - AOS; serre; NW - 37,6 m² - 90°							
gevelhoek	25,00	0,150		13. binnensp. op gevel (uitw.)	n.v.t.		
kozijn	51,20	0,100		8. kozijnaansluiting	n.v.t.		
zo serregevel - AOS; serre; ZO - 146,4 m² - 90°							
gevelhoek	35,00	0,150		13. binnensp. op gevel (uitw.)	n.v.t.		
kozijn	88,60	0,100		8. kozijnaansluiting	n.v.t.		
no serregevel - AOS; serre; NO - 106,5 m² - 90°							
kozijn	44,40	0,100		8. kozijnaansluiting	n.v.t.		
zw serregevel - AOS; serre; ZW - 106,5 m² - 90°							
kozijn	63,40	0,100		8. kozijnaansluiting	n.v.t.		

Transmissiegegevens rekenzone serre								
constructie	A [m²]	R_c [m²K/W]	U [W/m²K]	g_{gl} [-]	$F_{ss;gl}$ [-]	zonwering	beschaduwing	toelichting
no gevel - buitenlucht, NO - 97,9 m² - 90°								
serrepui/dek	97,90		5,80	0,80		nee	minimale belem.	
zw gevel - buitenlucht, ZW - 97,9 m² - 90°								
serrepui/dek	66,50		5,80	0,80		nee	minimale belem.	
serrepui/dek onder zonnepaneel	31,40		5,80	0,25		nee	minimale belem.	
nw gevel - buitenlucht, NW - 70,4 m² - 90°								
serrepui/dek	70,40		5,80	0,80		nee	minimale belem.	
zo gevel - buitenlucht, ZO - 214,6 m² - 90°								
serrepui/dek	214,60		5,80	0,80		nee	minimale belem.	
zw serredek - buitenlucht, ZW - 56,0 m² - 20°								
serrepui/dek onder zonnepaneel	56,00		5,80	0,25		nee	minimale belem.	

Transmissiegegevens rekenzone serre								
constructie	A [m²]	R_c [m²K/W]	U [W/m²K]	g_{gl} [-]	$F_{ss;gl}$ [-]	zonwering	beschaduwing	toelichting
no serredek - buitenlucht, NO - 56,0 m² - 20°								
serrepui/dek	56,00		5,80	0,80		nee	minimale belem.	

Kenmerken zontoetreding AOS

totaal geprojecteerde oppervlakte van de daglichtopening in de AOS	*225,00*
gemiddelde oriëntatie	*buitenlucht, ZO*
gemiddelde helling	*30*
beschaduwing	*01. minimale belem.*

Lineaire transmissiegegevens rekenzone serre							
constructie	l [m]	$\psi_{(e)}$ [W/m¹K]	ψ_{gr} [W/m¹K]	omschrijving	+25%	ε [m²/m¹]	toelichting
no gevel - buitenlucht, NO - 97,9 m² - 90°							
kozijn	28,80	0,100		8. kozijnaansluiting	n.v.t.		
zw gevel - buitenlucht, ZW - 97,9 m² - 90°							
kozijn	28,80	0,100		8. kozijnaansluiting	n.v.t.		
zw serredek - buitenlucht, ZW - 56,0 m² - 20°							
kozijn	93,00	0,100		8. kozijnaansluiting	n.v.t.		

Verwarming- en warmtapwatersystemen

verwarming/warmtapwater 1

Opwekking

type opwekker	*externe warmtelevering*
toepassingsklasse (CW-klasse)	*4 (CW 4, 5 en 6)*
aantal opwekkers	*2*
hoeveelheid energie t.b.v. verwarming per toestel ($Q_{H;dis;nren;an}$)	*12.475 MJ*
hoeveelheid energie t.b.v. warmtapwater per toestel ($Q_{W;dis;nren;an}$)	*9.550 MJ*
opwekkingsrendement verwarming - externe warmtelevering ($\eta_{H;gen}$)	*1,000*
opwekkingsrendement warmtapwater - externe warmtelevering ($\eta_{W;gen}$)	*1,000*

Kenmerken afgiftesysteem verwarming

Type warmteafgifte (in woonkamer)					
type warmteafgifte	positie	hoogte	R_c	$\theta_{em;avg}$	$\eta_{H;em}$
vloer- en/of wandverwarming en/of betonkernactivering	buitenvloer of buitenwand	< 8 m	≥ 2,5 m²K/W	n.v.t.	1,00

regeling warmteafgifte aanwezig	*ja*
individuele bemetering	*ja*
afgifterendement ($\eta_{H;em}$)	*1,000*

Kenmerken distributiesysteem verwarming

ongeïsoleerde verdeler / verzamelaar aanwezig	*nee*
buffervat buiten verwarmde ruimte aanwezig	*nee*
verwarmingsleidingen in onverwarmde ruimten en/of kruipruimte	*nee*
distributierendement ($\eta_{H;dis}$)	*1,000*

Kenmerken tapwatersysteem

aantal woningbouw-eenheden aangesloten op systeem	*2*
warmtapwatersysteem ten behoeve van	*keuken en badruimte*
gemiddelde leidinglengte naar badruimte	*forfaitair*
gemiddelde leidinglengte naar aanrecht	*forfaitair*
inwendige diameter leiding naar aanrecht	*≤ 10 mm*
afgifterendement warmtapwater ($\eta_{W;em}$)	*0,742*

Kenmerken distributiesysteem tapwater

individuele afleverset	*ja*
afleverset aangesloten op	*HT*
distributierendement warmtapwater ($\eta_{W;dis}$)	*0,750*

Douchewarmteterugwinning

douchewarmteterugwinning	*ja*
type douchewarmtewisselaar	*DWTW (forfaitair)*
aangesloten op	*aangesloten op koudepoort douchemengkraan en inlaat toestel*

Zonneboiler

zonneboiler	*nee*

Hulpenergie verwarming

hoofdcirculatiepomp aanwezig	*ja*
hoofdcirculatiepomp voorzien van pompregeling	*ja*
aanvullende circulatiepomp aanwezig	*nee*
aantal toestellen met waakvlam	*0*
afleverset met elektronica	*ja*

Aangesloten rekenzones

woonfunctie

Ventilatie

ventilatie 1

ventilatiesysteem	*Dc. mechanische toe- en afvoer - centraal*
systeemvariant	*Brink Renovent HR Medium, met bypass*
luchtvolumestroomfactor voor warmte- en koudebehoefte (f_{sys})	*1,00 (forfaitair conform systeemvariant D2b2 NEN 8088-1)*
correctiefactor regelsysteem voor warmte- en koudebehoefte (f_{reg})	*1,00 (forfaitair conform systeemvariant D2b2 NEN 8088-1)*

Kenmerken ventilatiesysteem

werkelijk geïnstalleerde ventilatiecapaciteit bekend	*nee*
luchtdichtheidsklasse ventilatiekanalen	*onbekend*

Passieve koeling

max. benutting geïnstal. ventilatiecapaciteit voor koudebehoefte	*ja*
max. benutting geïnstal. spuicapaciteit voor koudebehoefte	*ja*

Kenmerken warmteterugwinning

rendement warmteterugwinning vlgs NEN 5138	*0,95*
rendement warmteterugwinning inclusief dissipatie	*ja*
praktijkrendementcorrectiefactor (f_{rend})	*0,90*
fractie lucht via bypass	*1*

Kenmerken ventilatoren

totaal nominaal vermogen (P_{nom}) centrale ventilatie-units	*130,00 W (2 units)*

Aangesloten rekenzones

woonfunctie

Zonnestroom

zonnestroom 1

PVT systeem	*geen PVT systeem*
piekvermogen per m²	*120 Wp/m² bepaald volgens NEN-EN-IEC 60904-1*

Zonnestroom eigenschappen				
ventilatie	A_{PV} [m²]	oriëntatie	helling [°]	beschaduwing
matig geventileerd - op dak/gevel, met spouw	25,60	ZW	20	minimale belemmering

Resultaten

Jaarlijkse hoeveelheid primaire energie voor de energiefunctie		
verwarming	$E_{H;P}$	28.699 MJ
warmtapwater	$E_{W;P}$	19.101 MJ
koeling	$E_{C;P}$	0 MJ
zomercomfort	$E_{SC;P}$	34.837 MJ
ventilatoren	$E_{V;P}$	4.870 MJ
verlichting	$E_{L;P}$	8.437 MJ
geëxporteerde warmte/koude	$E_{P;exp;T}$	0 MJ
geëxporteerde elektriciteit	$E_{P;exp;el}$	0 MJ
op eigen perceel opgew. elektr. - installaties	$E_{P;pr;EPus;el}$	12.067 MJ
op eigen perceel opgew. elektr. - huishoudelijk	$E_{P;pr;nEPus;el}$	10.999 MJ

Oppervlakten		
totale gebruiksoppervlakte	$A_{g;tot}$	183,10 m²
totale verliesoppervlakte	A_{ls}	571,74 m²

Energiegebruik		
elektriciteitsgebruik	$E_{EPdel;el}$	4.321 kWh
externe warmte- en/of koudelevering	$E_{EPdel;dh}$	44,1 GJ
energiegebruik overig energiedragers	$E_{EPdel;aeq}$	0 m³aeq
specifieke elektriciteitsgebruik	$e_{EPdel;el}$	23,6 kWh/m²
specifieke externe warmte- en/of koudelevering	$e_{EPdel;dh}$	0,2 GJ/m²
specifieke energiegebruik overig energiedr.	$a_{EPdel;aeq}$	0,0 m³aeq/m²

Elektriciteitsproductie		
op eigen perceel opgewekte elektriciteit	$E_{P;pr;us;el}$	2.503 kWh

CO_2-emissie		
CO_2-emissie	m_{co2}	5.630 kg

Energieprestatie		
specifieke energieprestatie	EP	398 MJ/m²
karakteristiek energiegebruik	E_{Ptot}	72.878 MJ
toelaatbaar karakteristiek energiegebruik	$E_{P;adm;tot;nb}$	74.015 MJ
energieprestatiecoëfficiënt	EPC	0,591 -
energieprestatiecoëfficiënt	EPC	0,60 -
energielabel		A++

Het gebouw voldoet aan de eisen inzake energieprestatie uit het Bouwbesluit 2012.

Uniec2.0.5 is gebaseerd op NEN 7120;2011 "Energieprestatie van gebouwen – bepalingsmethode" inclusief correctieblad C2 en NEN 8088-1 "Ventilatie en luchtdoorlatendheid van gebouwen - Bepalingsmethode voor de toevoerluchttemperatuur gecorrigeerde ventilatie- en infiltratieluchtvolumestromen voor energieprestatieberekeningen - Deel 1: Rekenmethode" inclusief correctieblad C1.

12.3.3 UNIEC CALCULATION (REUSED VENTILATION ENERGY CALCULATION) :

The following energy performance calculation was conducted to record the difference in ventilation demand if heat recovery is not applied.

Resultaten

Jaarlijkse hoeveelheid primaire energie voor de energiefunctie		
verwarming (excl. hulpenergie)	$E_{H;P}$	38.505 MJ
hulpenergie		3.959 MJ
warmtapwater (excl. hulpenergie)	$E_{W;P}$	19.101 MJ
hulpenergie		0 MJ
koeling (excl. hulpenergie)	$E_{C;P}$	0 MJ
hulpenergie		0 MJ
zomercomfort	$E_{SC;P}$	31.759 MJ
ventilatoren	$E_{V;P}$	9.627 MJ
verlichting	$E_{L;P}$	8.437 MJ
geëxporteerde elektriciteit	$E_{P;exp;el}$	0 MJ
op eigen perceel opgewekte elektriciteit	$E_{P;pr;us;el}$	23.066 MJ
Oppervlakten		
totale gebruiksoppervlakte	$A_{g;tot}$	183,10 m²
totale verliesoppervlakte	A_{ls}	571,74 m²
Externe warmtelevering gebruik		
gebouwgebonden installaties		57.606 GJ
Elektriciteitsgebruik		
gebouwgebonden installaties		5.836 kWh
niet-gebouwgebonden apparatuur (stelpost)		5.133 kWh
op eigen perceel opgewekte elektriciteit		2.503 kWh
TOTAAL		8.466 kWh
CO_2-emissie		
CO_2-emissie	m_{co2}	6.935 kg
Energieprestatie		
specifieke energieprestatie	EP	482 MJ/m²
karakteristiek energiegebruik	E_{Ptot}	88.323 MJ
toelaatbaar karakteristiek energiegebruik	$E_{P;adm;tot;nb}$	74.015 MJ
energieprestatiecoëfficiënt	EPC	0,716 -
energieprestatiecoëfficiënt	EPC	0,72 -

In de berekening wordt gebruik gemaakt van het principe met een getrapte EPC eis conform Bouwbesluit 2012 artikel 5.2 lid 3.
Het gebouw voldoet aan de 1e trap eis (1,33 x BB eis) inzake energieprestatie uit het Bouwbesluit 2012.
Bij deze berekening behoort tevens een berekening van de 2e trap eis.

Uniec 2.0 is gebaseerd op NEN 7120;2011 "Energieprestatie van gebouwen – bepalingsmethode" inclusief correctieblad C2 en NEN 8088-1 "Ventilatie en luchtdoorlatendheid van gebouwen - Bepalingsmethode voor de toevoerluchttemperatuur gecorrigeerde ventilatie- en infiltratieluchtvolumestromen voor energieprestatieberekeningen - Deel 1: Rekenmethode" inclusief correctieblad C1.

12.3.4 BUILDING PERMIT DRAWINGS :

1. Material Specifications per component layer:

Renvooi: materialen en tekensymbolen

wanden (boven is buiten)

Kas gevel
50 mm aluminium stijl- en regelwerk
4 mm gevel - gehard glas

Buitenwand
40 mm houtvezelplaat isolatie
180 mm houten stijl- en regelwerk + celulose isolatie
15 mm gipsvezelplaat

vloeren en daken

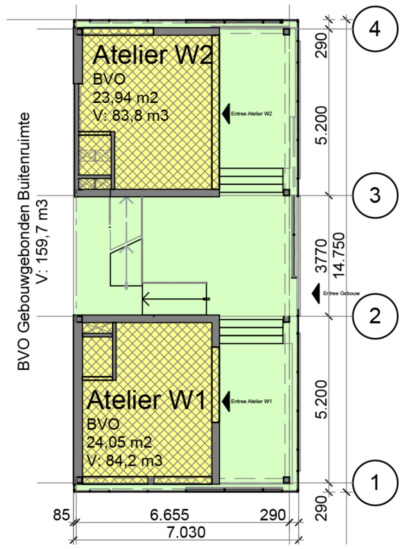
Kas dak
50 mm aluminium stijl- en regelwerk
6mm dak - gelaagd glas

Begane grond vloer
70 mm cementdekvloer, gewapend vloerverwarming
200 mm gewapend beton kanaalplaat
200 mm EPS islolatie

2. BVO (ground floor):

Brutto Vloeroppervlak BVO

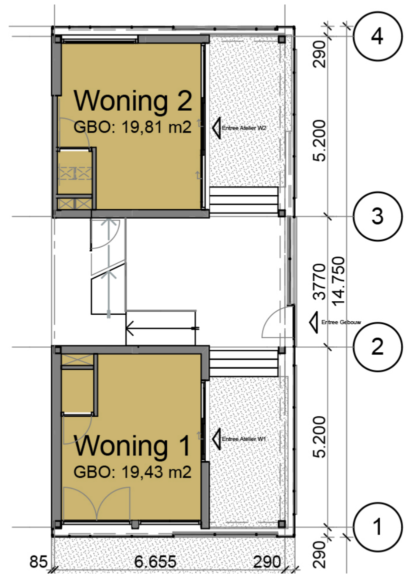
BVO		Verdieping	Oppervlak
	Atelier W1	Begane grond	24,0
	Atelier W2	Begane grond	23,9
	Woning W1	1e verdieping	58,7
	Woning W1	2e verdieping	25,0
	Woning W2	2e verdieping	28,1
	Woning W2	3e verdieping	58,2
			217,9 m²



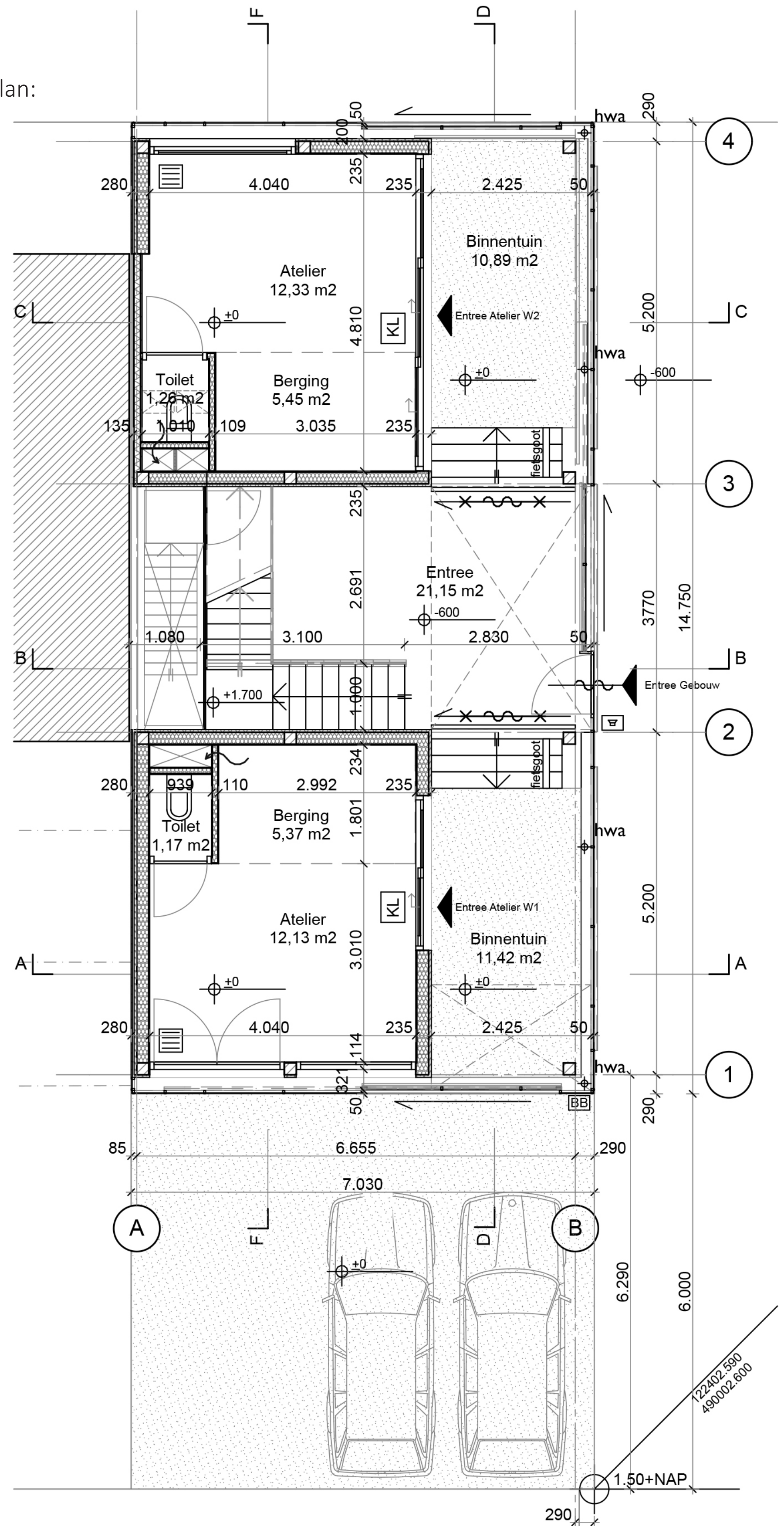
3. GBO (ground floor):

Gebruiksoppervlak GBO

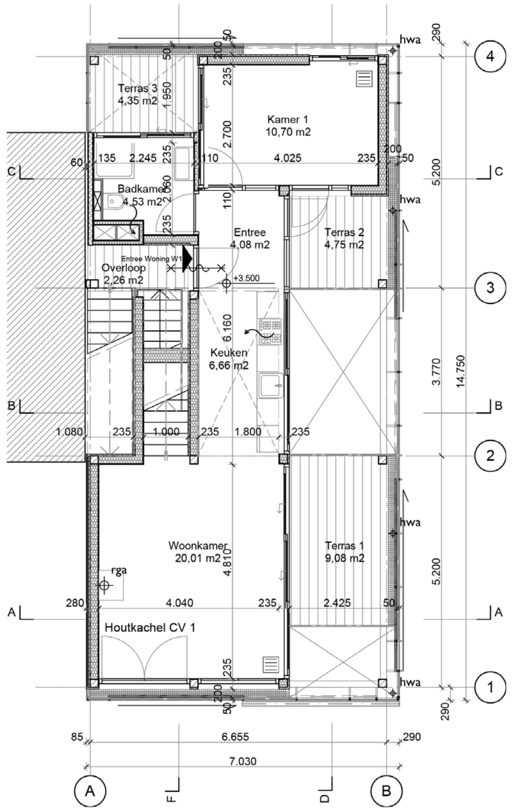
	Verdieping	Oppervlak
Woning 1		
	Begane grond	19,4
	1e verdieping	49,0
	2e verdieping	21,1
		89,5 m²
Woning 2		
	Begane grond	19,8
	2e verdieping	24,4
	3e verdieping	49,4
		93,6 m²
		183,1 m²

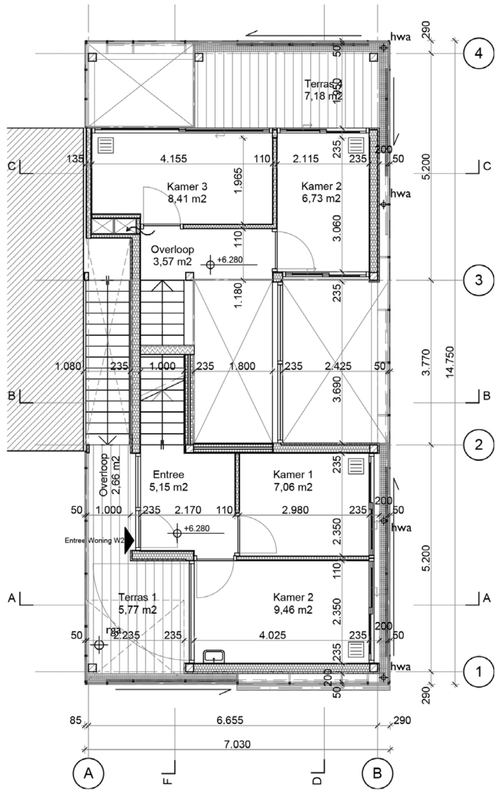


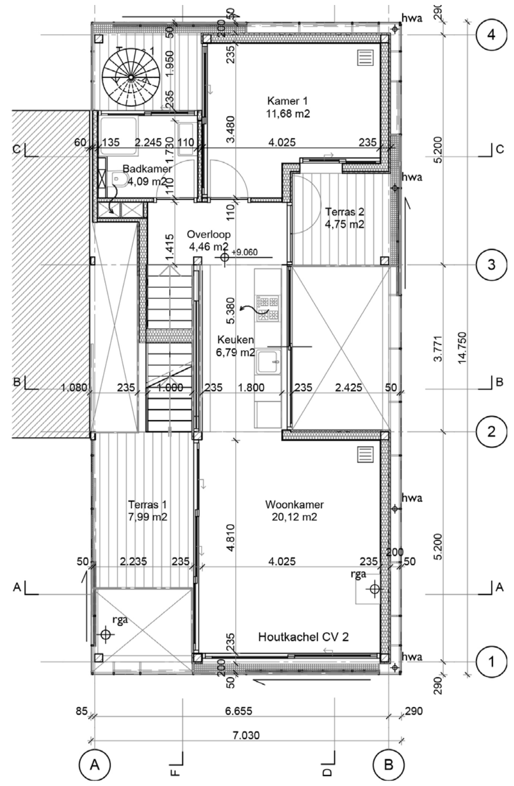
4. Ground floor plan:



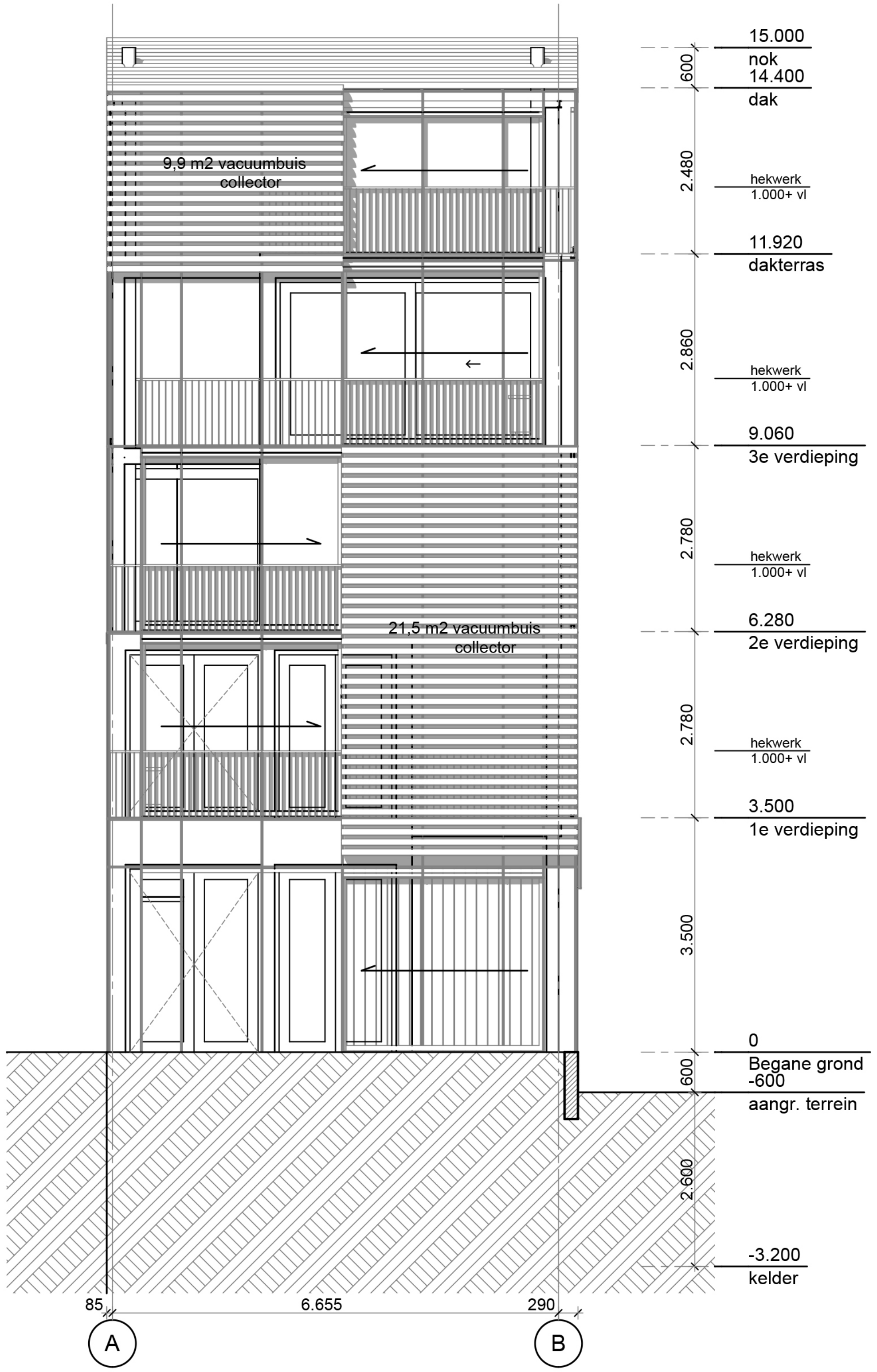
5. First, second and third floor plan:


1e verdieping


2e verdieping


3e verdieping

6. South-west elevation:



12.3.5 MPG CALCULATIONS :

1. Facade:

MRPI
milieu relevante product informatie

Rapportage Freetool MRPI Milieuprestatie Gebouw

In deze rapportage zijn de resultaten en de invoer opgenomen van de milieuprestatieberekening gebouw van Case 1. De resultaten zijn verdeeld naar de verplichte milieuprestatieberekening voor het bouwbesluit op basis van afdeling 5.2 en naar de MPG score. Tot slot is een verantwoording voor de berekening opgenomen.

Algemene gegevens

Naam project:	Case 1
Organisatie:	TU Delft
Gebruiksfunctie:	Woongebouw
Bvo:	218 m2
Levensduur:	75 jaar
Datum rapportage:	02-05-2019

Resultaat bouwbesluit

In bijlage I is een overzicht opgenomen van de geselecteerde producten inclusief hoeveelheden en eventuele dimensies van het product. In de onderstaande tabel zijn de relevante resultaten opgenomen.

Milieu-impact	berekende waarde	eenheid
Uitputting abiotische grondstoffen (excl. fossiel)	0	kg Sb eq./ m2 BVO*jaar
Uitputting fossiele energiedragers	0,016	kg Sb eq./ m2 BVO*jaar
Klimaatverandering (100 jaar)	2,38	kg CO2 eq./ m2 BVO*jaar

De berekende resultaten zijn direct gekoppeld aan de in bijlage I opgenomen producten, een afwijkende materialisatie of productkeuze heeft invloed op de berekening. Indien in het verdere ontwerp- en bouwproces andere materiaalkeuzes worden gemaakt dient de milieuprestatie opnieuw berekend te worden.

Resultaat MPG-score

In bijlage I is een overzicht opgenomen van de geselecteerde producten inclusief hoeveelheden en eventuele dimensies van het product. De MPG-score van Case 1 is 0,44 € / m2 BVO. In de onderstaande tabel is dit resultaat weergegeven naar de verschillende bouwdelen.

Bouwdeel	Resultaat
Fundering	0%
Vloeren	0%
Draagconstructie	0%
Gevels	97,2%
Daken	0%
Installaties	0%
Inbouw	2,8%

Rapportage Freetool MRPI Milieuprestatie Gebouw

Bijlage I, invoer berekening

- ongetoetst
- getoetst

Fundering		
Vloeren		
Draagconstructie		
Gevels		
Gevels, dicht		
Spouwwanden, binnenblad, systeem	HSB element; Europees naaldhouten multiplex en gipsplaat; duurzame bosbouw [180]	268,8 m2
Isolatielagen	Houtvezelplaat (115 kg/m3); db [5.2]	268,8 m2
Isolatielagen	Celluloseplaten, incl dampremmende PE-folie [4.5]	268,8 m2
Gevels, open		
Kozijnen	Aluminium vast en/of draaiend, geanodiseerd	150,6 m2
Ramen	Europees loofhout; geschilderd, acryl; duurzame bosbouw	33,06 m2
Beglazing	HR++ (dubbel) glas; coating / gasvulling (argon) , 4/16/4 mm	132,24 m2
Beglazing	Enkel glas; droog beglaasd [4]	225 m2
Daken		
Installaties		
Inbouw		
Binnenwanden		
Niet dragende wanden, systeem, bekledingen	Gipskartonplaat [15]	239 m2

2. Energy installations:

Rapportage Freetool MRPI Milieuprestatie Gebouw

In deze rapportage zijn de resultaten en de invoer opgenomen van de milieuprestatieberekening gebouw van Case 1. De resultaten zijn verdeeld naar de verplichte milieuprestatieberekening voor het bouwbesluit op basis van afdeling 5.2 en naar de MPG score. Tot slot is een verantwoording voor de berekening opgenomen.

Algemene gegevens

Naam project:	Case 1
Organisatie:	TU Delft
Gebruiksfunctie:	Woongebouw
Bvo:	218 m2
Levensduur:	75 jaar
Datum rapportage:	02-05-2019

Resultaat bouwbesluit

In bijlage I is een overzicht opgenomen van de geselecteerde producten inclusief hoeveelheden en eventuele dimensies van het product. In de onderstaande tabel zijn de relevante resultaten opgenomen.

Milieu-impact	berekende waarde	eenheid
Uitputting abiotische grondstoffen (excl. fossiel)	0	kg Sb eq./ m2 BVO*jaar
Uitputting fossiele energiedragers	0,021	kg Sb eq./ m2 BVO*jaar
Klimaatverandering (100 jaar)	3,09	kg CO2 eq./ m2 BVO*jaar

De berekende resultaten zijn direct gekoppeld aan de in bijlage I opgenomen producten, een afwijkende materialisatie of productkeuze heeft invloed op de berekening. Indien in het verdere ontwerp- en bouwproces andere materiaalkeuzes worden gemaakt dient de milieuprestatie opnieuw berekend te worden.

Resultaat MPG-score

In bijlage I is een overzicht opgenomen van de geselecteerde producten inclusief hoeveelheden en eventuele dimensies van het product. De MPG-score van Case 1 is 0,5 € / m2 BVO. In de onderstaande tabel is dit resultaat weergegeven naar de verschillende bouwdelen.

Bouwdeel	Resultaat
Fundering	0%
Vloeren	0%
Draagconstructie	0%
Gevels	0%
Daken	0%
Installaties	100%
Inbouw	0%

Rapportage Freetool MRPI Milieuprestatie Gebouw

Bijlage I, invoer berekening

- ongetoetst
- getoetst

Fundering

Vloeren

Draagconstructie

Gevels

Daken

Installaties

Warmtelevering

Zonneverwarminginstallaties	Individuele zvi; collector+opslagvat (bij 4m2 collector)	82 m2
Warmtelevering, extern	Regionaal niveau; opwekking + distributie, 1 MJ (forfaitair)	44100 MJ

Elektrische installatie

Elektriciteitsopwekkingsystemen	PV,mono-Si; plat dak; incl. inverter+steun+kabels	25 m2

Inbouw

3. Ground floor:

Rapportage Freetool MRPI Milieuprestatie Gebouw

In deze rapportage zijn de resultaten en de invoer opgenomen van de milieuprestatieberekening gebouw van Case 1. De resultaten zijn verdeeld naar de verplichte milieuprestatieberekening voor het bouwbesluit op basis van afdeling 5.2 en naar de MPG score. Tot slot is een verantwoording voor de berekening opgenomen.

Algemene gegevens

Naam project:	Case 1
Organisatie:	TU Delft
Gebruiksfunctie:	Woongebouw
Bvo:	47 m2
Levensduur:	75 jaar
Datum rapportage:	12-05-2019

Resultaat bouwbesluit

In bijlage I is een overzicht opgenomen van de geselecteerde producten inclusief hoeveelheden en eventuele dimensies van het product. In de onderstaande tabel zijn de relevante resultaten opgenomen.

Milieu-impact	berekende waarde	eenheid
Uitputting abiotische grondstoffen (excl. fossiel)	0	kg Sb eq./ m2 BVO*jaar
Uitputting fossiele energiedragers	0,006	kg Sb eq./ m2 BVO*jaar
Klimaatverandering (100 jaar)	1,25	kg CO2 eq./ m2 BVO*jaar

De berekende resultaten zijn direct gekoppeld aan de in bijlage I opgenomen producten, een afwijkende materialisatie of productkeuze heeft invloed op de berekening. Indien in het verdere ontwerp- en bouwproces andere materiaalkeuzes worden gemaakt dient de milieuprestatie opnieuw berekend te worden.

Resultaat MPG-score

In bijlage I is een overzicht opgenomen van de geselecteerde producten inclusief hoeveelheden en eventuele dimensies van het product. De MPG-score van Case 1 is 0,11 € / m2 BVO. In de onderstaande tabel is dit resultaat weergegeven naar de verschillende bouwdelen.

Bouwdeel	Resultaat
Fundering	0%
Vloeren	95,9%
Draagconstructie	0%
Gevels	0%
Daken	0%
Installaties	4,1%
Inbouw	0%

Rapportage Freetool MRPI Milieuprestatie Gebouw

Bijlage I, invoer berekening

- ongetoetst
- getoetst

Fundering		
Vloeren		
Vloeren, begane grond		
Vloeren, vrijdragend	Kanaalplaat, prefab beton; AB-FAB [200] (getoetst)	47,14 m2
Isolatielagen	EPS [5] (ongetoetst)	47,14 m2
Dekvloeren	NeMO zandcement dekvloer C12 [70] (getoetst)	39,24 m2
Draagconstructie		
Gevels		
Daken		
Installaties		
Warmtelevering		
Warmteafgiftesystemen	Vloerverwarming 95 W/m2; leidingen:kunststof (ongetoetst)	39,24 m2gbo
Inbouw		

12.4 APPENDIX D : ASSESSMENT CASE 02

12.4.1 QUESTIONNAIRE RESPONSE :

TU Delft Delft University of Technology

Inventarisatie van energie-efficiëntie en circulariteit van zelfbouw woningen in Buiksloterham

Beste bewoner, de volgende vragenlijst is bedoeld als hulp bij een onderzoek naar de energie-efficiëntie en circulariteit van nieuwe woningen in Buiksloterham. De verzamelde informatie zal worden gebruikt voor een inventaris van nieuwe technologieën die in Buiksloterham worden toegepast, met als doel richtlijnen en tips voor nieuwe bewoners te kunnen geven om Buiksloterham Circulair te maken! Alvast hartelijk dank voor het invullen van de enquete.

Bouwjaar

2016

Aantal bewoners in de woning

4

Architecturale gegevens

Bruto vloeroppervlak (m^2)

Ruimte van alle gebruikte ruimtes + gangen + trappen

Hoe tevreden bent u met het thermisch comfort van uw huis?

	1	2	3	4	5	6	7	8	9	10	
Zeer ontevreden	○	○	○	○	○	○	○	○	◉	○	Zeer tevreden

Andere aanvullende informatie:

lots of stories still not finished

Aanvullende informatie

Indien u uw jaarlijkse energiegebruik wee ten dit wilt delen, wilt u dan onderstaande vragen invullen:

Wat is uw maandelijkse energierekening (bij benadering)?

300

Indien bekend: Bij externe warmtelevering/standsverwarming: jaarlijkse warmtegebruik [.....GJ/jaar]

pellets 2500 kg

Bouwaanvraag tekening

Upload Bouwaanvraag tekening

Mocht u een bouwaanvraag tekening hebben en willen uploaden, dan kunnen wij daar de benodigde informatie uit halen en hoeft u verder geen vragen over materialen in te vullen.

1223-20-BA01 (3) -...

Heb je een Bouwaanvraag tekening geüpload? *

Als u het tekening hebt geüpload, worden de materiaalvragen automatisch overgeslagen

(x) Ja

( ) Nee

Materiële keuze

Wordt een van de volgende aspecten in aanmerking genomen bij het kiezen van de materialen voor het huis? (meerdere antwoorden mogelijk):

	Kosten	Gezondheid	Circulariteit	Energiezuinigheid	Milieubelasting materialen	Geen van bovenstaande	Niet van toepassin
Fundering					✓		
Begane grond			✓				
Bovenste verdiepi			✓				
Dragende structuur					✓		
Gevel			✓				
Binnenmuren					✓		
Dakopbouw					✓		

Andere aanvullende informatie:

veel materialen v marktplaats

Indien bekend: In welke categorieën is het bouwafval gescheiden? (meerdere antwoorden mogelijk)

- [x] Houtafval - voorbeeld: hout, multiplex
- [x] Metaalresten - voorbeeld: HVAC-kanaalsecties, aluminiumplaten
- [x] Staalschroot - voorbeeld: wapeningsstaven
- [x] Beton - voorbeeld: betonschilfers, betonblokken
- [x] Bakstenen
- [x] Gipsplaten / scheidingsbordafval
- [x] Tegels en / of keramiek
- [x] Glas
- [x] Kunststoffen - voorbeeld: buizen
- [x] Other: alles

Duurzame maatregelen

Uitwerken van andere duurzame maatregelen geïmplementeerd in het huis.

using second hand

12.4.2 EPC CALCULATION REPORT :

Uniec 2.0

Huis A - Huis A (woonfunctie)
eerste trap
0,30

Algemene gegevens

projectomschrijving	*Huis A (woonfunctie)*
variant	*eerste trap*
adres	
postcode / plaats	
bouwjaar	
categorie	*woningbouw*
aantal woningbouw-eenheden in berekening	*1*
gebruiksfunctie	*woonfunctie*
datum	
opmerkingen	

Indeling gebouw

Eigenschappen rekenzones

type rekenzone	omschrijving	interne warmtecapaciteit	A_g [m²]
verwarmde zone	woning	traditioneel, gemengd zwaar	64,84

Infiltratie

meetwaarde voor infiltratie $q_{v;10;spec}$	*nee*
lengte van het gebouw	*10,00 m*
breedte van het gebouw	*8,40 m*
hoogte van het gebouw	*10,72 m*

Eigenschappen infiltratie

rekenzone	gebouwtype	$q_{v;10;spec}$ [dm³/s per m²]
woning	grondgebonden gebouw, tussenligging, plat dak	0,49

Open verbrandingstoestellen

Het gebouw bevat geen open verbrandingstoestellen.

Bouwkundige transmissiegegevens

Transmissiegegevens rekenzone woning							
constructie	A [m²]	R_c [m²K/W]	U [W/m²K]	g_{gl} [-]	zonwering	beschaduwing	toelichting
Plat dak - buitenlucht, HOR, dak - 57,2 m² - 0°							
plat dak	57,17	6,00				minimale belem.	
Voorgevel - buitenlucht, ZW - 27,9 m² - 90°							
gevels	13,12	5,00				minimale belem.	
merk D/E (1 stuks)	14,78		1,64	0,60	ja	volledige belem.	
Achtergevel - buitenlucht, NO - 39,0 m² - 90°							
gevels	33,16	5,00				minimale belem.	
merk U (1 stuks)	5,79		1,64	0,60	nee	minimale belem.	
Rechterzijgevel - buitenlucht, ZO - 26,7 m² - 90°							
gevels	26,69	5,00				minimale belem.	

De lineaire warmteverliezen zijn berekend volgens de forfaitaire methode uit hoofdstuk 13 van NEN 1068.

Verwarming- en warmtapwatersystemen

verwarming/warmtapwater 1

Opwekking

type opwekker	*biomassaketel (vaste brandstof)*
rendement op onderwaarde vlgs NEN-EN 303-5;1999	*rendement op onderwaarde ≥ 105,3%*
getrapte eis	*1e trap (Bouwbesluit EPC-eis x 1,33)*
aantal biomassaketels	*1*
vermogen biomassa ketel	*4,0 kW*
β-factor biomassa ketel	*1,33*
type bijverwarming	*geen bijverwarming*
warmtapwaterbereiding	*warmtewisselaar*
opwekkingsrendement verwarming - biomassaketel ($\eta_{H;gen}$)	*0,975*
opwekkingsrendement - bijverwarming ($\eta_{H;gen}$)	*0,000*
opwekkingsrendement warmtapwater - biomassaketel ($\eta_{H;gen}$)	*0,975*

mate van isolatie warmwatervoorraad

Kenmerken afgiftesysteem verwarming

Type warmteafgifte (in woonkamer)					
type warmteafgifte	positie	hoogte	R_c	$\theta_{em;avg}$	$\eta_{H;em}$
vloer- en/of wandverwarming en/of betonkernactivering	buitenvloer of buitenwand	< 8 m	≥ 2,5 m²K/W	n.v.t.	1,00

regeling warmteafgifte aanwezig	*ja*
afgifterendement ($\eta_{H;em}$)	*1,000*

Kenmerken distributiesysteem verwarming

ongeïsoleerde verdeler / verzamelaar aanwezig	*nee*
buffervat buiten verwarmde ruimte aanwezig	*nee*
verwarmingsleidingen in onverwarmde ruimten en/of kruipruimte	*nee*
distributierendement ($\eta_{H;dis}$)	*1,000*

Kenmerken tapwatersysteem

aantal woningbouw-eenheden aangesloten op systeem	*1*
warmtapwatersysteem ten behoeve van	*keuken en badruimte*
gemiddelde leidinglengte naar badruimte	*forfaitair*
gemiddelde leidinglengte naar aanrecht	*forfaitair*
inwendige diameter leiding naar aanrecht	*≤ 10 mm*
afgifterendement warmtapwater ($\eta_{W;em}$)	*0,742*

Douchewarmteterugwinning

douchewarmteterugwinning	*ja*
type douchewarmtewisselaar	*Heitech Technea Douchepijp-wtw-V3 - 2,1 m*
aangesloten op	*aangesloten op koudepoort douchemengkraan en inlaat toestel*

Zonneboiler

zonneboiler	*ja*
zonneboiler(combi) ten behoeve van:	*warmtapwater*
collector	*Acol ≤ 10,0 m²*
zonnekeur	*nee*
PVT systeem	*geen PVT systeem*
thermosifon of ICS systeem	*nee*

Zonneboiler eigenschappen							
oriëntatie	helling [°]	A_{col} [m²]	V_{sto} [dm³]	V_{bu} [dm³]	$P_{defrost}$ [W]	aantal ZB	beschaduwing
Z	20	4,50	100	0	0	1	minimale belemmering

Hulpenergie verwarming

hoofdcirculatiepomp aanwezig	*nee*
aanvullende circulatiepomp aanwezig	*nee*
ondergrens van de modulatie van de brander (m_{min})	*0,4*

Aangesloten rekenzones

woning

Ventilatie

ventilatie 1

Ventilatiesysteem

ventilatiesysteem	*C. natuurlijke toevoer en mechanische afvoer*
systeemvariant	*C3b winddrukgestuurde toevoer, tijdsturing op afvoer zonder zonering*
luchtvolumestroomfactor voor warmte- en koudebehoefte (f_{sys})	*1,09*
correctiefactor regelsysteem voor warmte- en koudebehoefte (f_{reg})	*0,69*

Kenmerken ventilatiesysteem

werkelijk geïnstalleerde ventilatiecapaciteit bekend	*nee*
warmtepompboiler(s) in gebouw	*nee*
luchtdichtheidsklasse ventilatiekanalen	*onbekend*

Passieve koeling

max. benutting geïnstal. ventilatiecapaciteit voor koudebehoefte	*ja*
max. benutting geïnstal. spuicapaciteit voor koudebehoefte	*ja*

Kenmerken ventilatoren

type ventilatoren (vermogen forfaitair)	*gelijkstroom*

Aangesloten rekenzones

woning

Zonnestroom

zonnestroom 1

PVT systeem	*geen PVT systeem*
type zonnestroompaneel	*monokristallijn silicium (135 Wp/m2)*

Zonnestroom eigenschappen

ventilatie	A_{PV} [m²]	oriëntatie	helling [°]	beschaduwing
sterk geventileerd - vrijstaand	9,26	Z	20	minimale belemmering

Resultaten

Jaarlijkse hoeveelheid primaire energie voor de energiefunctie		
verwarming (excl. hulpenergie)	$E_{H;P}$	12.345 MJ
hulpenergie		892 MJ
warmtapwater (excl. hulpenergie)	$E_{W;P}$	3.928 MJ
hulpenergie		1.024 MJ
koeling (excl. hulpenergie)	$E_{C;P}$	0 MJ
hulpenergie		0 MJ
zomercomfort	$E_{SC;P}$	860 MJ
ventilatoren	$E_{V;P}$	823 MJ
verlichting	$E_{L;P}$	2.988 MJ
geëxporteerde elektriciteit	$E_{P;exp;el}$	0 MJ
op eigen perceel opgewekte elektriciteit	$E_{P;pr;us;el}$	10.418 MJ

Oppervlakten		
totale gebruiksoppervlakte	$A_{g;tot}$	64,84 m²
totale verliesoppervlakte	A_{ls}	150,71 m²

Biomassa (vaste brandstof) gebruik	
gebouwgebonden installaties	16.272 MJ

Elektriciteitsgebruik	
gebouwgebonden installaties	715 kWh
niet-gebouwgebonden apparatuur (stelpost)	1.818 kWh
op eigen perceel opgewekte elektriciteit	1.130 kWh
TOTAAL	1.402 kWh

CO_2-emissie		
CO_2-emissie	m_{co2}	-235 kg

Energieprestatie		
specifieke energieprestatie	EP	192 MJ/m²
karakteristiek energiegebruik	E_{Ptot}	12.441 MJ
toelaatbaar karakteristiek energiegebruik	$E_{P;adm;tot;nb}$	25.611 MJ
energieprestatiecoëfficiënt	EPC	0,292 -
energieprestatiecoëfficiënt	EPC	0,30 -

Uniec2.0.7 is gebaseerd op NEN 7120;2011 "Energieprestatie van gebouwen – bepalingsmethode" inclusief correctieblad C2 en NEN 8088-1 "Ventilatie en luchtdoorlatendheid van gebouwen - Bepalingsmethode voor de toevoerluchttemperatuur gecorrigeerde ventilatie- en infiltratieluchtvolumestromen voor energieprestatieberekeningen - Deel 1: Rekenmethode" inclusief correctieblad C1.

Uniec[2.0]

Huis A - Huis A (woonfunctie) tweede trap	-0,08

Algemene gegevens

projectomschrijving	*Huis A (woonfunctie)*
variant	*tweede trap*
adres	
postcode / plaats	
bouwjaar	
categorie	*woningbouw*
aantal woningbouw-eenheden in berekening	*1*
gebruiksfunctie	*woonfunctie*
datum	
opmerkingen	

Indeling gebouw

Eigenschappen rekenzones

type rekenzone	omschrijving	interne warmtecapaciteit	A_g [m²]
verwarmde zone	woning	traditioneel, gemengd zwaar	64,84

Infiltratie

meetwaarde voor infiltratie $q_{v;10;spec}$	*nee*
lengte van het gebouw	*10,00 m*
breedte van het gebouw	*8,40 m*
hoogte van het gebouw	*10,72 m*

Eigenschappen infiltratie

rekenzone	gebouwtype	$q_{v;10;spec}$ [dm³/s per m²]
woning	grondgebonden gebouw, tussenligging, plat dak	0,49

Open verbrandingstoestellen

Het gebouw bevat geen open verbrandingstoestellen.

Bouwkundige transmissiegegevens

Transmissiegegevens rekenzone woning

constructie	A [m²]	R_c [m²K/W]	U [W/m²K]	g_{gl} [-]	zonwering	beschaduwing	toelichting
Plat dak - buitenlucht, HOR, dak - 57,2 m² - 0°							
plat dak	57,17	6,00				minimale belem.	
Voorgevel - buitenlucht, ZW - 27,9 m² - 90°							
gevels	13,12	5,00				minimale belem.	
merk D/E (1 stuks)	14,78		1,64	0,60	ja	volledige belem.	
Achtergevel - buitenlucht, NO - 39,0 m² - 90°							
gevels	33,16	5,00				minimale belem.	
merk U (1 stuks)	5,79		1,64	0,60	nee	minimale belem.	
Rechterzijgevel - buitenlucht, ZO - 26,7 m² - 90°							
gevels	26,69	5,00				minimale belem.	

De lineaire warmteverliezen zijn berekend volgens de forfaitaire methode uit hoofdstuk 13 van NEN 1068.

Verwarming- en warmtapwatersystemen

verwarming/warmtapwater 1

Opwekking

type opwekker	*biomassaketel (vaste brandstof)*
rendement op onderwaarde vlgs NEN-EN 303-5;1999	*rendement op onderwaarde ≥ 105,3%*
getrapte eis	*2e trap (Bouwbesluit EPC-eis)*
aantal biomassaketels	*1*
vermogen biomassa ketel	*4,0 kW*
β-factor biomassa ketel	*1,33*
type bijverwarming	*geen bijverwarming*
warmtapwaterbereiding	*warmtewisselaar*
opwekkingsrendement verwarming - biomassaketel ($\eta_{H;gen}$)	*0,975*
opwekkingsrendement - bijverwarming ($\eta_{H;gen}$)	*0,000*
opwekkingsrendement warmtapwater - biomassaketel ($\eta_{H;gen}$)	*0,975*

mate van isolatie warmwatervoorraad

Kenmerken afgiftesysteem verwarming

Type warmteafgifte (in woonkamer)					
type warmteafgifte	positie	hoogte	R_c	$\theta_{em;avg}$	$\eta_{H;em}$
vloer- en/of wandverwarming en/of betonkernactivering	buitenvloer of buitenwand	< 8 m	≥ 2,5 m²K/W	n.v.t.	1,00

regeling warmteafgifte aanwezig	*ja*
afgifterendement ($\eta_{H;em}$)	*1,000*

Kenmerken distributiesysteem verwarming

ongeïsoleerde verdeler / verzamelaar aanwezig	*nee*
buffervat buiten verwarmde ruimte aanwezig	*nee*
verwarmingsleidingen in onverwarmde ruimten en/of kruipruimte	*nee*
distributierendement ($\eta_{H;dis}$)	*1,000*

Kenmerken tapwatersysteem

aantal woningbouw-eenheden aangesloten op systeem	*1*
warmtapwatersysteem ten behoeve van	*keuken en badruimte*
gemiddelde leidinglengte naar badruimte	*forfaitair*
gemiddelde leidinglengte naar aanrecht	*forfaitair*
inwendige diameter leiding naar aanrecht	*≤ 10 mm*
afgifterendement warmtapwater ($\eta_{W;em}$)	*0,742*

Douchewarmteterugwinning

douchewarmteterugwinning	*ja*
type douchewarmtewisselaar	*Heitech Technea Douchepijp-wtw-V3 - 2,1 m*
aangesloten op	*aangesloten op koudepoort douchemengkraan en inlaat toestel*

Zonneboiler

zonneboiler	*ja*
zonneboiler(combi) ten behoeve van:	*warmtapwater*
collector	*Acol ≤ 10,0 m²*
zonnekeur	*nee*
PVT systeem	*geen PVT systeem*
thermosifon of ICS systeem	*nee*

Zonneboiler eigenschappen							
oriëntatie	helling [°]	A_{col} [m²]	V_{sto} [dm³]	V_{bu} [dm³]	$P_{defrost}$ [W]	aantal ZB	beschaduwing
Z	20	4,50	100	0	0	1	minimale belemmering

Hulpenergie verwarming

hoofdcirculatiepomp aanwezig	*nee*
aanvullende circulatiepomp aanwezig	*nee*
ondergrens van de modulatie van de brander (m_{min})	*0,4*

Aangesloten rekenzones

woning

Ventilatie

ventilatie 1

Ventilatiesysteem

ventilatiesysteem	*C. natuurlijke toevoer en mechanische afvoer*
systeemvariant	*C3b winddrukgestuurde toevoer, tijdsturing op afvoer zonder zonering*
luchtvolumestroomfactor voor warmte- en koudebehoefte (f_{sys})	*1,09*
correctiefactor regelsysteem voor warmte- en koudebehoefte (f_{reg})	*0,69*

Kenmerken ventilatiesysteem

werkelijk geïnstalleerde ventilatiecapaciteit bekend	*nee*
warmtepompboiler(s) in gebouw	*nee*
luchtdichtheidsklasse ventilatiekanalen	*onbekend*

Passieve koeling

max. benutting geïnstal. ventilatiecapaciteit voor koudebehoefte	*ja*
max. benutting geïnstal. spuicapaciteit voor koudebehoefte	*ja*

Kenmerken ventilatoren

type ventilatoren (vermogen forfaitair)	*gelijkstroom*

Aangesloten rekenzones

woning

Zonnestroom

zonnestroom 1

PVT systeem	*geen PVT systeem*
type zonnestroompaneel	*monokristallijn silicium (135 Wp/m2)*

Zonnestroom eigenschappen				
ventilatie	A_{PV} [m²]	oriëntatie	helling [°]	beschaduwing
sterk geventileerd - vrijstaand	9,26	Z	20	minimale belemmering

Resultaten

Jaarlijkse hoeveelheid primaire energie voor de energiefunctie		
verwarming (excl. hulpenergie)	$E_{H;P}$	0 MJ
hulpenergie		892 MJ
warmtapwater (excl. hulpenergie)	$E_{W;P}$	0 MJ
hulpenergie		1.024 MJ
koeling (excl. hulpenergie)	$E_{C;P}$	0 MJ
hulpenergie		0 MJ
zomercomfort	$E_{SC;P}$	860 MJ
ventilatoren	$E_{V;P}$	823 MJ
verlichting	$E_{L;P}$	2.988 MJ
geëxporteerde elektriciteit	$E_{P;exp;el}$	0 MJ
op eigen perceel opgewekte elektriciteit	$E_{P;pr;us;el}$	10.418 MJ

Oppervlakten		
totale gebruiksoppervlakte	$A_{g;tot}$	64,84 m²
totale verliesoppervlakte	A_{ls}	150,71 m²

Biomassa (vaste brandstof) gebruik	
gebouwgebonden installaties	16.272 MJ

Elektriciteitsgebruik	
gebouwgebonden installaties	715 kWh
niet-gebouwgebonden apparatuur (stelpost)	1.818 kWh
op eigen perceel opgewekte elektriciteit	1.130 kWh
TOTAAL	1.402 kWh

CO_2-emissie		
CO_2-emissie	m_{co2}	-235 kg

Energieprestatie		
specifieke energieprestatie	EP	-59 MJ/m²
karakteristiek energiegebruik	E_{Ptot}	-3.831 MJ
toelaatbaar karakteristiek energiegebruik	$E_{P;adm;tot;nb}$	25.611 MJ
energieprestatiecoëfficiënt	EPC	-0,089 -
energieprestatiecoëfficiënt	EPC	-0,08 -

Uniec2.0.7 is gebaseerd op NEN 7120;2011 "Energieprestatie van gebouwen – bepalingsmethode" inclusief correctieblad C2 en NEN 8088-1 "Ventilatie en luchtdoorlatendheid van gebouwen - Bepalingsmethode voor de toevoerluchttemperatuur gecorrigeerde ventilatie- en infiltratieluchtvolumestromen voor energieprestatieberekeningen - Deel 1: Rekenmethode" inclusief correctieblad C1.

12.4.3 UNIEC CALCULATION (REUSED VENTILATION ENERGY CALCULATION) :

Resultaten

Jaarlijkse hoeveelheid primaire energie voor de energiefunctie		
verwarming (excl. hulpenergie)	$E_{H;P}$	0 MJ
hulpenergie		900 MJ
warmtapwater (excl. hulpenergie)	$E_{W;P}$	0 MJ
hulpenergie		1.024 MJ
koeling (excl. hulpenergie)	$E_{C;P}$	0 MJ
hulpenergie		0 MJ
zomercomfort	$E_{SC;P}$	1.905 MJ
ventilatoren	$E_{V;P}$	3.173 MJ
verlichting	$E_{L;P}$	2.988 MJ
geëxporteerde elektriciteit	$E_{P;exp;el}$	0 MJ
op eigen perceel opgewekte elektriciteit	$E_{P;pr;us;el}$	10.418 MJ

Oppervlakten		
totale gebruiksoppervlakte	$A_{g;tot}$	64,84 m²
totale verliesoppervlakte	A_{ls}	150,80 m²

Biomassa (vaste brandstof) gebruik	
gebouwgebonden installaties	17.473 MJ

Elektriciteitsgebruik	
gebouwgebonden installaties	1.084 kWh
niet-gebouwgebonden apparatuur (stelpost)	1.818 kWh
op eigen perceel opgewekte elektriciteit	1.130 kWh
TOTAAL	1.771 kWh

CO_2-emissie		
CO_2-emissie	m_{co2}	-26 kg

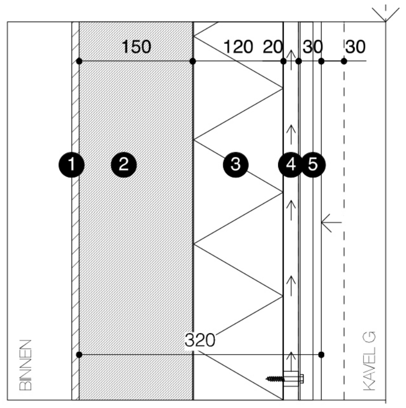
Energieprestatie		
specifieke energieprestatie	EP	-7 MJ/m²
karakteristiek energiegebruik	E_{Ptot}	-429 MJ
toelaatbaar karakteristiek energiegebruik	$E_{P;adm;tot;nb}$	25.615 MJ
energieprestatiecoëfficiënt	EPC	-0,010 -
energieprestatiecoëfficiënt	EPC	-0,01 -

In de berekening wordt gebruik gemaakt van het principe met een getrapte EPC eis conform Bouwbesluit 2012 artikel 5.2 lid 3.
Het gebouw voldoet aan de 2e trap eis inzake energieprestatie uit het Bouwbesluit 2012.
Bij deze berekening behoort tevens een berekening van de 1e trap eis.

Uniec 2.0 is gebaseerd op NEN 7120;2011 "Energieprestatie van gebouwen – bepalingsmethode" inclusief correctieblad C2 en NEN 8088-1 "Ventilatie en luchtdoorlatendheid van gebouwen - Bepalingsmethode voor de toevoerluchttemperatuur gecorrigeerde ventilatie- en infiltratieluchtvolumestromen voor energieprestatieberekeningen - Deel 1: Rekenmethode" inclusief correctieblad C1.

12.4.4 BUILDING PERMIT DRAWINGS :

1. Material Specifications per component layer:



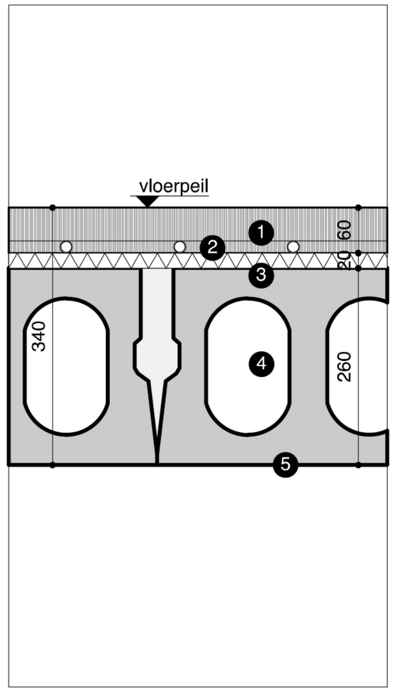
M2.Pg

GEVEL - kavel G
1 - stucwerk 10mm
2 - kalkzandsteen o.g. 150mm
3 - sandwichpaneel 120mm
4 - geventileerde spouw
5 - staalprofielplaat Pyramid 19/470
e - erfgrens kavel G

NB! *eis Rc≥5,0 aan te tonen door aannemer*

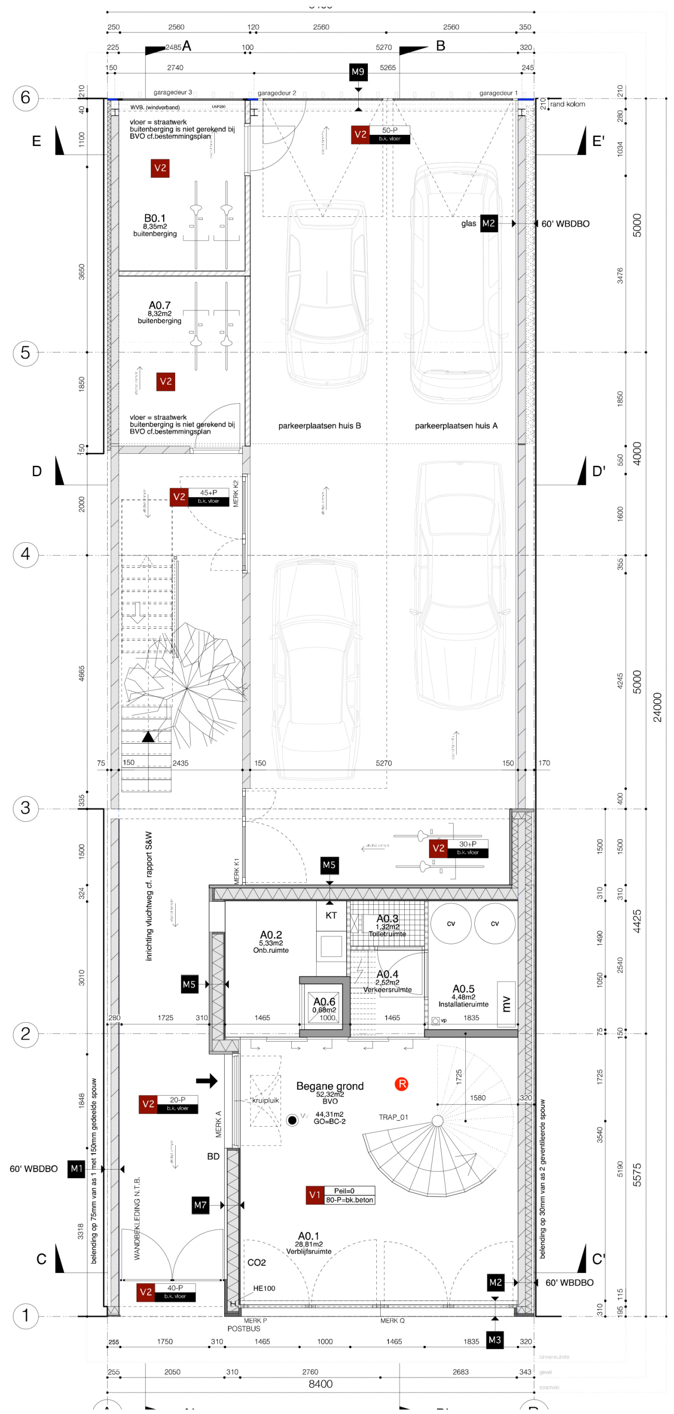
Pyramid 19/470

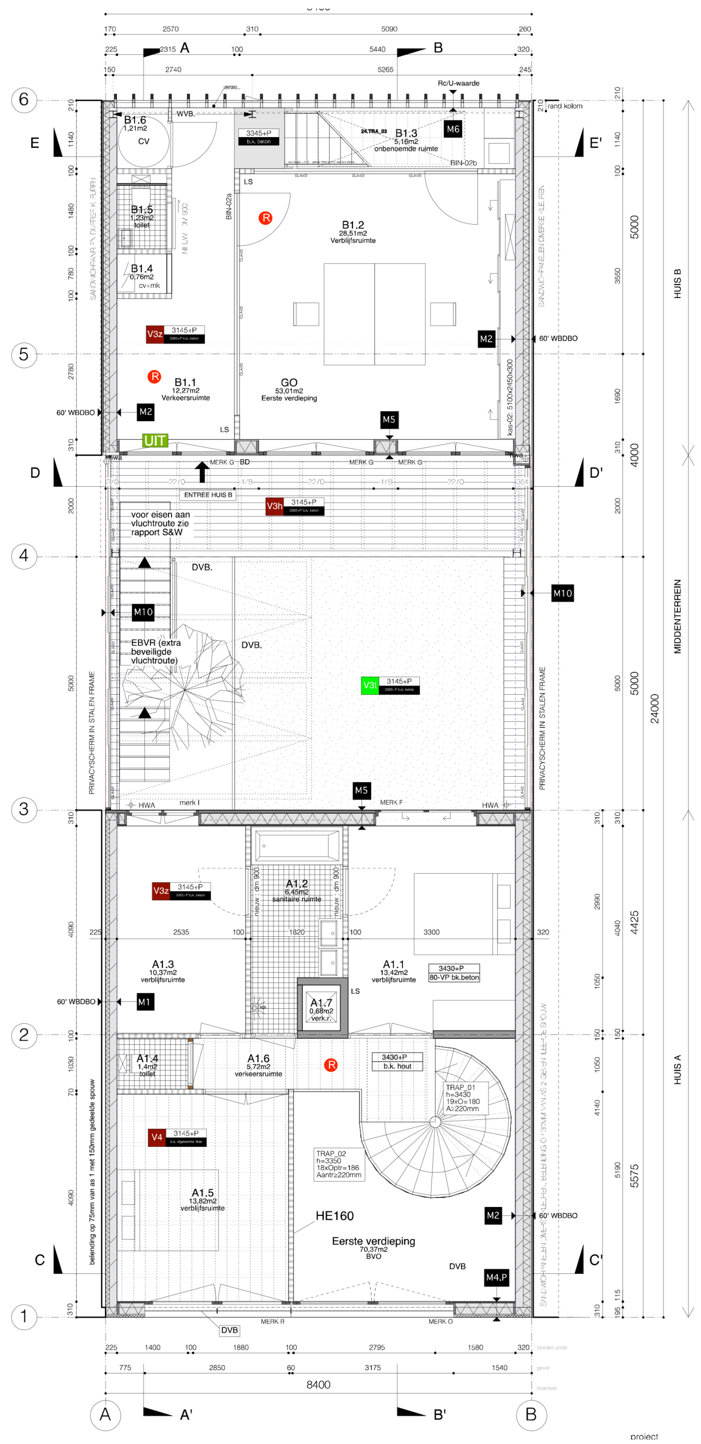
Staalprofielplaat gevelbekleding
toe te passen als esthetische bekleding
in zijgevels en in zuidgevel.

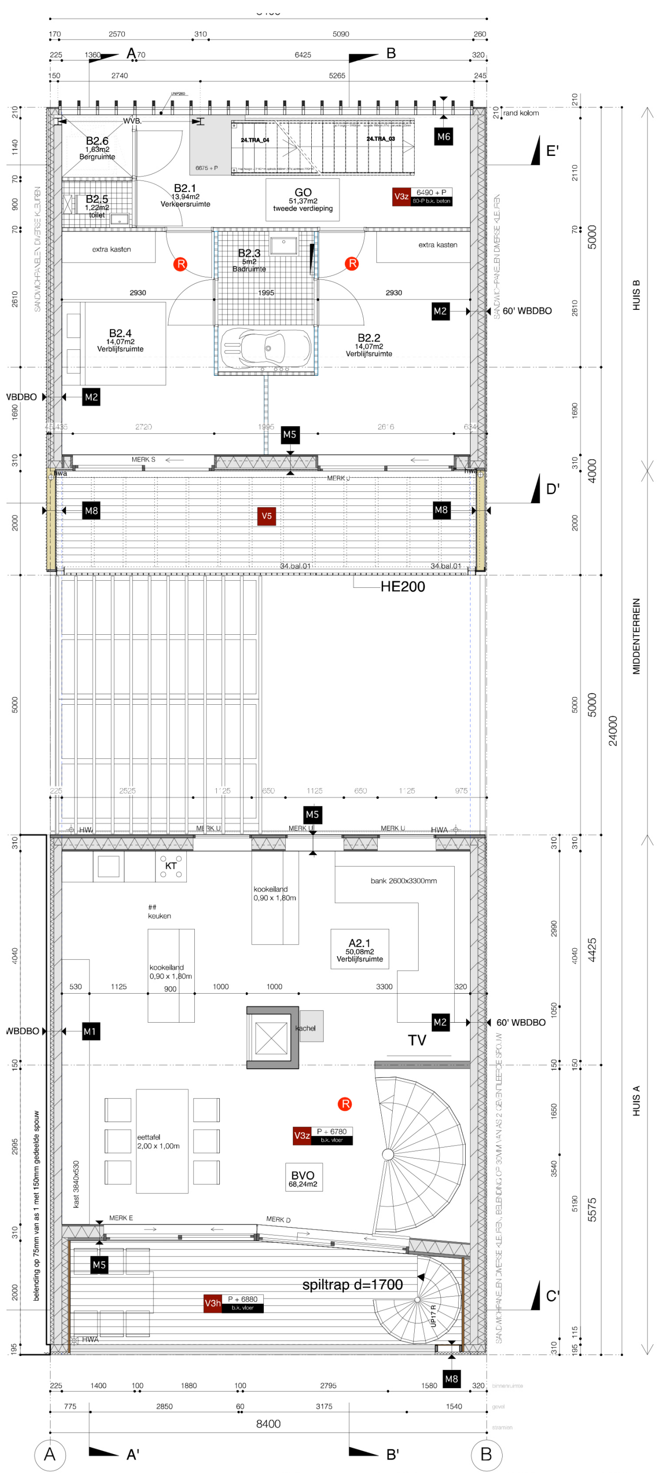


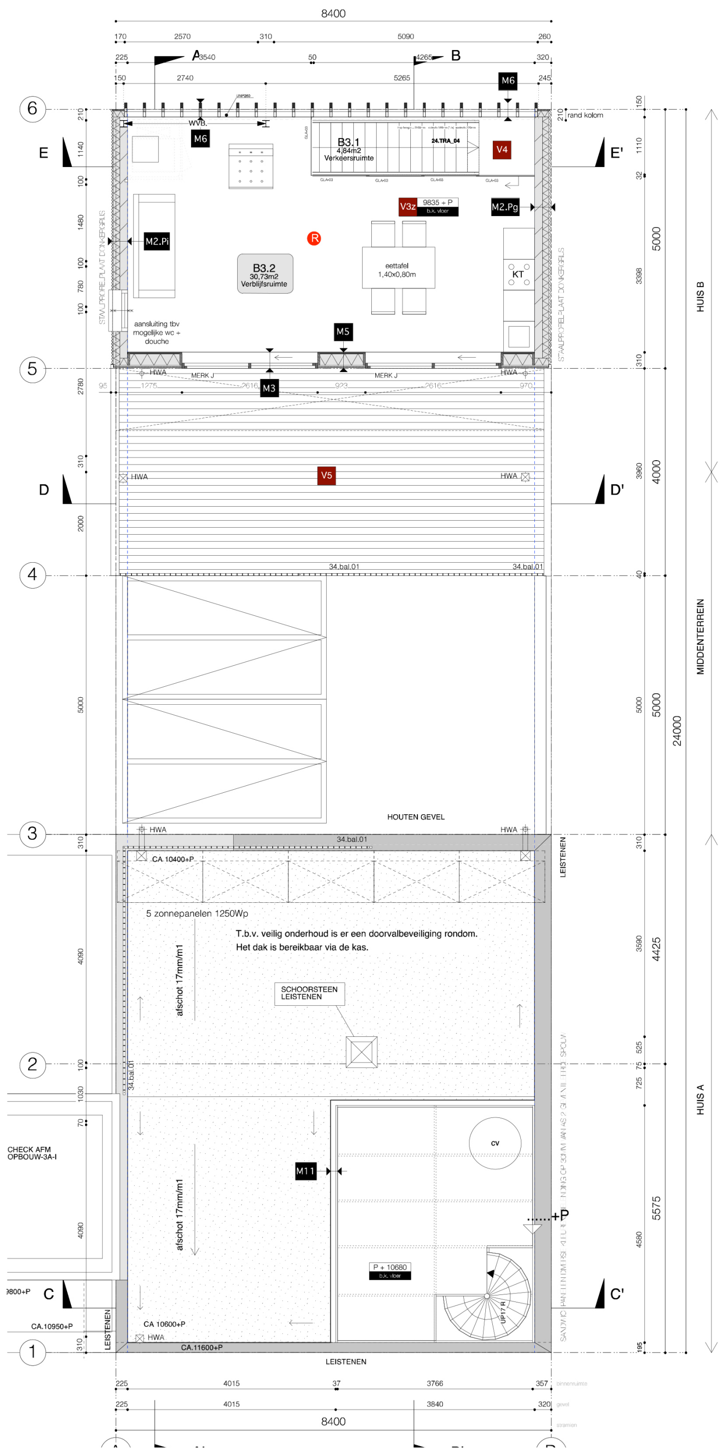
V3

KANAALPLAATVLOER
1 - afwerklaag (zwevende dekvloer)
2 - vloerverwarming
3 - 20mm isolatie
4 - kanaalplaatvloer
5 - plafond kale beton









12.4.5 MPG CALCULATIONS :

1. Floor:

MRPI
milieu relevante product informatie

Rapportage Freetool MRPI Milieuprestatie Gebouw

In deze rapportage zijn de resultaten en de invoer opgenomen van de milieuprestatieberekening gebouw van Case 2. De resultaten zijn verdeeld naar de verplichte milieuprestatieberekening voor het bouwbesluit op basis van afdeling 5.2 en naar de MPG score. Tot slot is een verantwoording voor de berekening opgenomen.

Algemene gegevens

Naam project:	Case 2
Organisatie:	TU Delft
Gebruiksfunctie:	Woongebouw
Bvo:	75 m2
Levensduur:	75 jaar
Datum rapportage:	02-05-2019

Resultaat bouwbesluit

In bijlage I is een overzicht opgenomen van de geselecteerde producten inclusief hoeveelheden en eventuele dimensies van het product. In de onderstaande tabel zijn de relevante resultaten opgenomen.

Milieu-impact	berekende waarde	eenheid
Uitputting abiotische grondstoffen (excl. fossiel)	0	kg Sb eq./ m2 BVO*jaar
Uitputting fossiele energiedragers	0,003	kg Sb eq./ m2 BVO*jaar
Klimaatverandering (100 jaar)	0,8	kg CO2 eq./ m2 BVO*jaar

De berekende resultaten zijn direct gekoppeld aan de in bijlage I opgenomen producten, een afwijkende materialisatie of productkeuze heeft invloed op de berekening. Indien in het verdere ontwerp- en bouwproces andere materiaalkeuzes worden gemaakt dient de milieuprestatie opnieuw berekend te worden.

Resultaat MPG-score

In bijlage I is een overzicht opgenomen van de geselecteerde producten inclusief hoeveelheden en eventuele dimensies van het product. De MPG-score van Case 2 is 0,07 € / m2 BVO. In de onderstaande tabel is dit resultaat weergegeven naar de verschillende bouwdelen.

Bouwdeel	Resultaat
Fundering	0%
Vloeren	100%
Draagconstructie	0%
Gevels	0%
Daken	0%
Installaties	0%
Inbouw	0%

Rapportage Freetool MRPI Milieuprestatie Gebouw

Bijlage I, invoer berekening

ongetoetst

getoetst

Fundering		
Vloeren		
Vloeren, verdieping		
Vloeren	Kanaalplaat, prefab beton; AB-FAB [260]	64,84 m2
Dekvloeren	NeMO zandcement dekvloer C12 [60]	64,84 m2
Draagconstructie		
Gevels		
Daken		
Installaties		
Inbouw		

2. Facade:

Rapportage Freetool MRPI Milieuprestatie Gebouw

In deze rapportage zijn de resultaten en de invoer opgenomen van de milieuprestatieberekening gebouw van Case 2. De resultaten zijn verdeeld naar de verplichte milieuprestatieberekening voor het bouwbesluit op basis van afdeling 5.2 en naar de MPG score. Tot slot is een verantwoording voor de berekening opgenomen.

Algemene gegevens

Naam project:	Case 2
Organisatie:	TU Delft
Gebruiksfunctie:	Woongebouw
Bvo:	75 m2
Levensduur:	75 jaar
Datum rapportage:	02-05-2019

Resultaat bouwbesluit

In bijlage I is een overzicht opgenomen van de geselecteerde producten inclusief hoeveelheden en eventuele dimensies van het product. In de onderstaande tabel zijn de relevante resultaten opgenomen.

Milieu-impact	berekende waarde	eenheid
Uitputting abiotische grondstoffen (excl. fossiel)	0	kg Sb eq./ m2 BVO*jaar
Uitputting fossiele energiedragers	0,016	kg Sb eq./ m2 BVO*jaar
Klimaatverandering (100 jaar)	2,4	kg CO2 eq./ m2 BVO*jaar

De berekende resultaten zijn direct gekoppeld aan de in bijlage I opgenomen producten, een afwijkende materialisatie of productkeuze heeft invloed op de berekening. Indien in het verdere ontwerp- en bouwproces andere materiaalkeuzes worden gemaakt dient de milieuprestatie opnieuw berekend te worden.

Resultaat MPG-score

In bijlage I is een overzicht opgenomen van de geselecteerde producten inclusief hoeveelheden en eventuele dimensies van het product. De MPG-score van Case 2 is 0,34 € / m2 BVO. In de onderstaande tabel is dit resultaat weergegeven naar de verschillende bouwdelen.

Bouwdeel	Resultaat
Fundering	0%
Vloeren	0%
Draagconstructie	0%
Gevels	5,7%
Daken	0%
Installaties	94,3%
Inbouw	0%

Rapportage Freetool MRPI Milieuprestatie Gebouw

Bijlage I, invoer berekening

ongetoetst

getoetst

Fundering

Vloeren

Draagconstructie

Gevels

Gevels, open		
Beglazing	HR++ (dubbel) glas; coating / gasvulling (argon) , 4/16/4 mm	5,79 m2

Daken

Installaties

Warmtelevering		
Zonneverwarminginstallaties	Individuele zvi; collector+opslagvat (bij 4m2 collector)	4,5 m2
Elektrische installatie		
Elektriciteitsopwekkingsystemen	PV,mono-Si; plat dak; incl. inverter+steun+kabels	9,3 m2

Inbouw

3. Energy installations:

Rapportage Freetool MRPI Milieuprestatie Gebouw

In deze rapportage zijn de resultaten en de invoer opgenomen van de milieuprestatieberekening gebouw van Case 2. De resultaten zijn verdeeld naar de verplichte milieuprestatieberekening voor het bouwbesluit op basis van afdeling 5.2 en naar de MPG score. Tot slot is een verantwoording voor de berekening opgenomen.

Algemene gegevens

Naam project:	Case 2
Organisatie:	TU Delft
Gebruiksfunctie:	Woongebouw
Bvo:	75 m2
Levensduur:	75 jaar
Datum rapportage:	02-05-2019

Resultaat bouwbesluit

In bijlage I is een overzicht opgenomen van de geselecteerde producten inclusief hoeveelheden en eventuele dimensies van het product. In de onderstaande tabel zijn de relevante resultaten opgenomen.

Milieu-impact	berekende waarde	eenheid
Uitputting abiotische grondstoffen (excl. fossiel)	0	kg Sb eq./ m2 BVO*jaar
Uitputting fossiele energiedragers	0,003	kg Sb eq./ m2 BVO*jaar
Klimaatverandering (100 jaar)	0,8	kg CO2 eq./ m2 BVO*jaar

De berekende resultaten zijn direct gekoppeld aan de in bijlage I opgenomen producten, een afwijkende materialisatie of productkeuze heeft invloed op de berekening. Indien in het verdere ontwerp- en bouwproces andere materiaalkeuzes worden gemaakt dient de milieuprestatie opnieuw berekend te worden.

Resultaat MPG-score

In bijlage I is een overzicht opgenomen van de geselecteerde producten inclusief hoeveelheden en eventuele dimensies van het product. De MPG-score van Case 2 is 0,07 € / m2 BVO. In de onderstaande tabel is dit resultaat weergegeven naar de verschillende bouwdelen.

Bouwdeel	Resultaat
Fundering	0%
Vloeren	100%
Draagconstructie	0%
Gevels	0%
Daken	0%
Installaties	0%
Inbouw	0%

Rapportage Freetool MRPI Milieuprestatie Gebouw

Bijlage I, invoer berekening

ongetoetst

getoetst

Fundering

Vloeren

Draagconstructie

Gevels

Daken

Installaties

Warmtelevering		
Zonneverwarminginstallaties	Individuele zvi; collector+opslagvat (bij 4m2 collector)	4,5 m2
Elektrische installatie		
Elektriciteitsopwekkingsystemen	PV,mono-Si; plat dak; incl. inverter+steun+kabels	9,3 m2

Inbouw

12.5 APPENDIX E : ASSESSMENT CASE 03

12.5.1 QUESTIONNAIRE RESPONSE :

TU Delft Delft University of Technology

Inventarisatie van energie-efficiëntie en circulariteit van zelfbouw woningen in Buiksloterham

Beste bewoner, de volgende vragenlijst is bedoeld als hulp bij een onderzoek naar de energie-efficiëntie en circulariteit van nieuwe woningen in Buiksloterham. De verzamelde informatie zal worden gebruikt voor een inventaris van nieuwe technologieën die in Buiksloterham worden toegepast, met als doel richtlijnen en tips voor nieuwe bewoners te kunnen geven om Buiksloterham Circulair te maken! Alvast hartelijk dank voor het invullen van de enquete.

Algemene informatie

Bouwjaar

2018-2019

Aantal bewoners in de woning

3 grondgebonden woningen 1-4 bewoners, 8 appartementen met 1-4 bewoners

Architecturale gegevens

Bruto vloeroppervlak (m^2)
Ruimte van alle gebruikte ruimtes + gangen + trappen

1500

Energie Prestatie Coefficient (EPC)

Energie Prestatie Coefficient (EPC) van het gebouw

0,15

Bouw eigenschappen

Is uw woning (gebouw), voor zover u weet, beter geïsoleerd dan volgens de normen uit het Bouwbesluit? *
Bouwbesluit standard: Vloer - Rc: 3,5, Dak: - Rc: 6,0, Gevel - Rc: 4,5 [m2K/W]

- (x) Ja
- ( ) Nee

Isolatie: Indien bekend, wat is de isoaltiewaarde van de gevel?

Rc = 4.5

Isolatie: Indien bekend, wat is de isoaltiewaarde van de dak?

Rc >=6

Beglazing: welk soort beglazing is in de woning gebruikt en wat is de Uvalue van deze beglazing?

Double glazing with U <=1.0

Warm water voor huishoudelijk gebruik

De volgende vragen hebben betrekking op het gebruik van warm water in de woning en het systeem dat wordt gebruikt om dit te produceren. U kunt meerdere opties aanvinken.

Type systeem

- [ ] Zonnecollector
- [x] Stadsverwarming
- [ ] Warmtepomp
- [ ] Other:

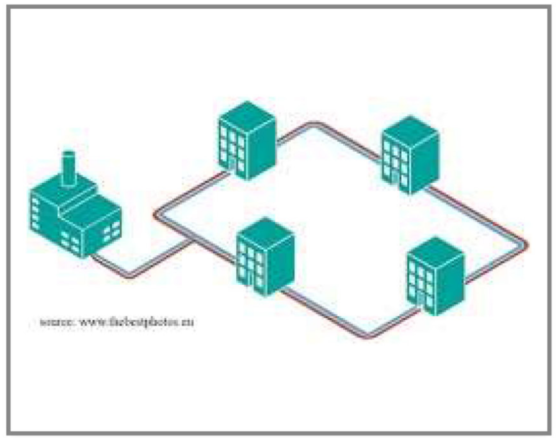
Heeft het huis een douche-warmteterugwinningssysteem?

- ( ) Ja
- (x) Nee

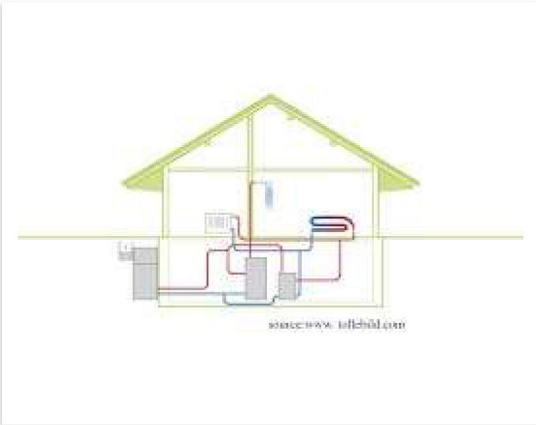
Hoe worden de kamers verwarmd?

- [x] Oppervlakteverwarming (vloeren / muren)

Wat is de warmtetoevoerbron voor ruimteverwarming?



- [x] Stadsverwarming



- [ ] Warmtepomp met luchtbron

Welke andere duurzame maatregelen zijn toegepast in de woning? (meerdere antwoorden mogelijk)

- [ ] Collectie van regenwater voor gebruik binnenshuis (bijv. toiletspoeling)
- [ ] Collective van regenwaater voor gebruik buitenshuis (bijv. tuin)
- [ ] Lokale zuivering en gebruik van grijswater
- [ ] Biogas reactor
- [x] Other:

Bevorderen biodiversiteit: nestkastjes en groenvoorzieningen (collectieve daktuin+ klimplanten langs kabels) Flexibeliteit: dankzij kolommenstructuur, scheiding drager en inbouwwanden, scheiding drager en installaties en flexibele plattegronden met zone voor werken aan huis (eigen toegang) Wateracummulatie in groendak boven parkeerruimte (regenwaterbuffer) Voorbereidingen aansluitpunten elektrisch rijden in stallingsgarage Demontabel en herbruikbaar betonnen casco Zonwering door overstekken (glazenwassersbalkons) en toepassing zonwerend glas

Zonnepanelen (PV)

Indien bekend: Wat is het totale oppervlak (m^2) aan zonnepanelen (PV) dat op de woning is geïnstalleerd?

78 m2 voor de appartementen, 15m2 voor de grondgebonden woningen

Indien bekend: Wat is het geïnstalleerde vermogen in wattpiek op het pand?

2850 voor grondgebondenwoningen, 14820 voor appartementen

Groendak

Indien bekend: Wat is de oppervlakte van het groendak van het huis?

ontwerp daktuin nog in ontwikkeling, oppervlakte groen +-130m2

Bovenste verdiepi

Zijn er hernieuwbare materialen / componenten / elementen gebruikt bij de bovenste verdiepi van het huis? *

Opmerking: geef alsjeblieft aan of ja als: het materiaal zelf is biologisch afbreekbaar en hernieuwbaar, of als het onderdeel kan worden gerecycled tot nieuwe componenten.

- (•) Ja
- ( ) Nee
- ( ) Onbekend

Constructiemateriaal + Isolatie + Andere extra laag + Chemische behandeling

* chemisch behandelingsvoorbeeld: Epoxy-coating

Prefab beton met demontabele verbindingen

Productnaam

demontabele verbindingen met Peikko systeem

Is bij de keuze van de materialen special rekening gehouden met een van de onderstaande aspecten (meerdere antwoorden mogelijk):

- [x] Kosten
- [ ] Gezondheid
- [x] Circulariteit
- [ ] Energiezuinigheid
- [ ] Milieubelasting materialen
- [ ] Geen van bovenstaande
- [x] Other:
  materiaalbesparing, dankzij prefabricage& voorspanning kon dun geconstrueerd worde
  -> minder materiaal benodigd

Materialen - Dragende structuur

Zijn er hernieuwbare materialen / componenten / elementen gebruikt bij de dragende structuur van het huis? *

Opmerking: geef alsjeblieft aan of ja als: het materiaal zelf is biologisch afbreekbaar en hernieuwbaar, of als h
onderdeel kan worden gerecycled tot nieuwe componenten.

- (●) Ja
- ( ) Nee
- ( ) Onbekend

Dragende structuur

Constructiemateriaal

prefab beton met demontabele verbindingen (kolommen, wanden, vloeren)

Productnaam

demontabele verbindingen met Peikko systeem

Is bij de keuze van de materialen special rekening gehouden met een van de onderstaande aspecten (meerdere antwoorden mogelijk):

- [x] Kosten
- [ ] Gezondheid
- [x] Circulariteit
- [ ] Energiezuinigheid
- [ ] Milieubelasting materialen
- [ ] Geen van bovenstaande
- [x] Other: materiaalbesparing door prefabricage

Gevel

Zijn er hernieuwbare materialen / componenten / elementen gebruikt bij de gevel van het huis? *

Opmerking: geef alsjeblieft aan of ja als: het materiaal zelf is biologisch afbreekbaar en hernieuwbaar, of als het onderdeel kan worden gerecycled tot nieuwe componenten.

- (●) Ja

Isolatiemateriaal + Andere extra laag + Chemische behandeling
* chemisch behandelingsvoorbeeld: glascoating

gevels van gebruikt hout: Azobé van oude damwandprofielen, onbehandeld, van zichzelf brandklasse B, steenwol isolatie, houten stijlen en demontabele stalen kaders rondom het hout

Is bij de keuze van de materialen special rekening gehouden met een van de onderstaande aspecten (meerdere antwoorden mogelijk):

- [x] Kosten
- [x] Gezondheid
- [x] Circulariteit
- [ ] Energiezuinigheid
- [x] Milieubelasting materialen
- [ ] Geen van bovenstaande
- [ ] Other:

Materialen - Binnenmuren

Zijn er hernieuwbare materialen / componenten / elementen gebruikt bij de binnenmuren van het huis? *
Opmerking: geef alsjeblieft aan of ja als: het materiaal zelf is biologisch afbreekbaar en hernieuwbaar, of als het onderdeel kan worden gerecycled tot nieuwe componenten.

- (●) Ja
- ( ) Nee
- ( ) Onbekend

Constructiemateriaal + Isolatie + Andere extra laag + Chemische behandeling
* chemisch behandelingsvoorbeeld: Verf, Dampdicht

gedeeltelijk prefab beton met demontabele verbindingen en gedeeltelijk metalstud (gedeeltelijk herbruik/recyclebaar)

Dakopbouw

Zijn er hernieuwbare materialen / componenten / elementen gebruikt bij de dakopbouw van het huis? *
Opmerking: geef alsjeblieft aan of ja als: het materiaal zelf is biologisch afbreekbaar en hernieuwbaar, of als het onderdeel kan worden gerecycled tot nieuwe componenten.

- (●) Ja
- ( ) Nee
- ( ) Onbekend

Constructiemateriaal + Isolatie + Andere extra laag + Chemische behandeling
* voorbeeld van chemische behandeling: waterdicht

prefab beton met demontabele verbindingen, EPS isolatie

Duurzame maatregelen

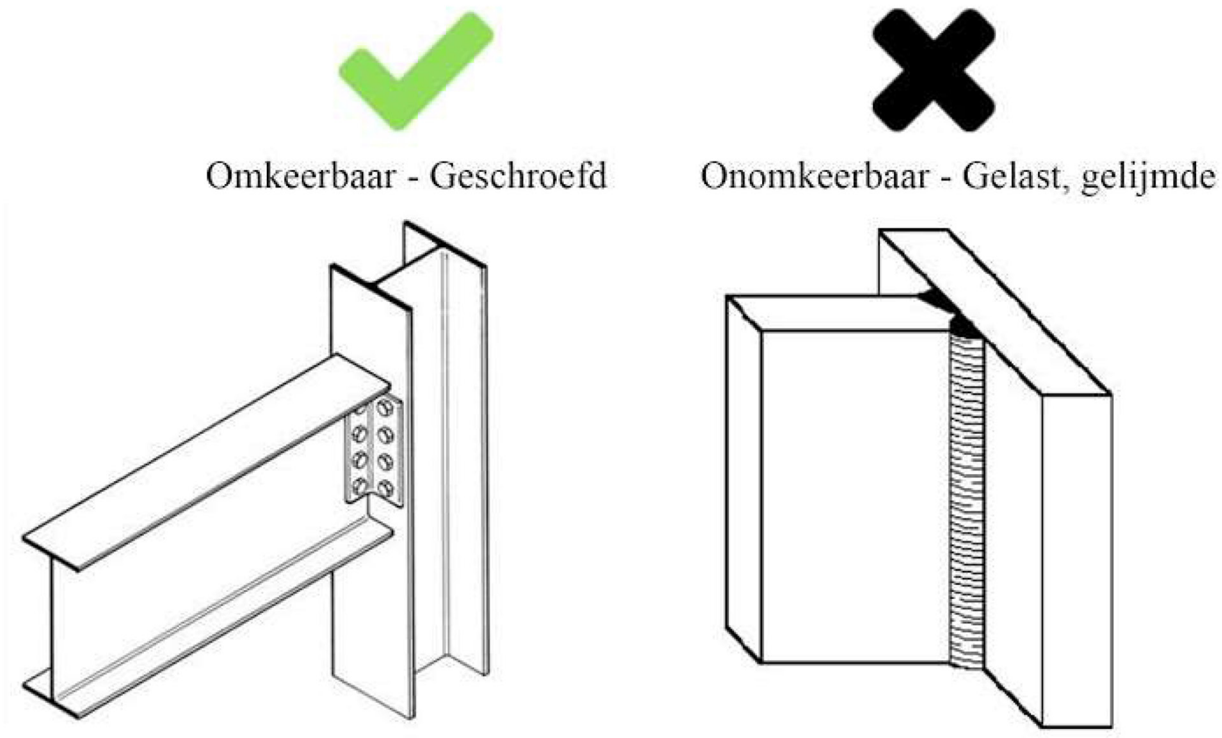
Zijn er andere duurzame maatregelen toegepast bij de bouw?

- (●) Ja
- ( ) Nee
- ( ) Onbekend

Uitwerken van andere duurzame maatregelen geïmplementeerd in het huis.

Toepassing van veel prefab producten (o.a. betonnen casco) -> kleinere foutmarge en daardoor minder afval, dunnere vloeren dankzij prefabricage (materiaalbesparing)

Voor zover u weet, zijn omkeerbaar verbindingen (bout- en moerverbinding of geschroefd enz.) Gebruikt voor het volgende:



	Ja	Nee	Onbekend
Begane grond	☑	☐	☐
Bovenste verdieping	☑	☐	☐
Gevel	☑	☐	☐
Binnenmuren	☑	☐	☐
Dakopbouw	☑	☐	☐

12.5.2 EPC CALCULATION :

Uniec 2.0

- Case 03 onbekend	0,15

Algemene gegevens

projectomschrijving	*Case 03*
variant	*onbekend*
adres	*Amsterdam*
postcode / plaats	
bouwjaar	*2018*
categorie	*woningbouw*
aantal woningbouw-eenheden in berekening	*11*
gebruiksfunctie	*woonfunctie*
datum	*19-06-2019*
opmerkingen	

Indeling gebouw

Eigenschappen rekenzones

type rekenzone	omschrijving	interne warmtecapaciteit	A_g [m²]	aantal woningbouw-eenheden
verwarmde zone	woning	traditioneel, gemengd zwaar	1.200,00	11

Infiltratie

meetwaarde voor infiltratie $q_{v;10;spec}$	*nee*
lengte van het gebouw	*15,00 m*
breedte van het gebouw	*15,00 m*
hoogte van het gebouw	*14,00 m*

Eigenschappen infiltratie

rekenzone	gebouwtype	$q_{v;10;spec}$ [dm³/s per m²]
woning	grondgebonden gebouw, tussenligging, plat dak of geen dak	0,49

Open verbrandingstoestellen

Het gebouw bevat geen open verbrandingstoestellen.

Bouwkundige transmissiegegevens

Transmissiegegevens rekenzone woning

constructie	A [m²]	R_c [m²K/W]	U [W/m²K]	g_{gl} [-]	zonwering	beschaduwing	toelichting
no gevel - buitenlucht, N - 135,0 m² - 90°							

Transmissiegegevens rekenzone woning							
constructie	A [m²]	R_c [m²K/W]	U [W/m²K]	g_{gl} [-]	zonwering	beschaduwing	toelichting
gevel	105,00	4,50				minimale belem.	
glazing	30,00		1,00	0,60	ja	minimale belem.	
zo gevel - buitenlucht, Z - 210,0 m² - 90°							
gevel	130,00	4,50				minimale belem.	
glazing	80,00		1,00	0,60	ja	minimale belem.	
plat dak - buitenlucht, HOR, dak - 225,0 m² - 0°							
dak	225,00	6,00				volledige belem.	
vloer - kruipruimte - 375,0 m²							
vloer	375,00	4,50					

De lineaire warmteverliezen zijn berekend volgens de forfaitaire methode uit hoofdstuk 13 van NEN 1068.

Lineaire transmissiegegevens rekenzone woning		
constructie	l [m]	toelichting
vloer - kruipruimte - 375,0 m²		
forfaitaire perimeter	15,00	

Verwarming- en warmtapwatersystemen

verwarming/warmtapwater 1

Opwekking

type opwekker	*externe warmtelevering*
regio	*Amsterdam*
warmteleveringssysteem	*Amsterdam West Noord - Westpoort Warmte - Afval Energiebedrijf - primair net - Nuon Warmte*
aantal afleversets	*11*
opwekkingsrendement verwarming – ext. warmtelev. ($\eta_{H;gen}$)	*2,225*
opwekkingsrendement warmtapwater – ext. warmtelev. ($\eta_{W;gen}$)	*2,225*

Kenmerken afgiftesysteem verwarming

Type warmteafgifte (in woonkamer)					
type warmteafgifte	positie	hoogte	R_c	$\theta_{em;avg}$	$\eta_{H;em}$
vloer- en/of wandverwarming en/of betonkernactivering	buitenvloer of buitenwand	< 8 m	≥ 2,5 m²K/W	n.v.t.	1,00

regeling warmteafgifte aanwezig	*ja*
individuele bemetering	*ja*
afgifterendement ($\eta_{H;em}$)	*1,000*

Kenmerken distributiesysteem verwarming

ongeïsoleerde verdeler / verzamelaar aanwezig	*nee*
buffervat buiten verwarmde ruimte aanwezig	*nee*
verwarmingsleidingen in onverwarmde ruimten en/of kruipruimte	*nee*
distributierendement ($\eta_{H;dis}$)	*1,000*

Kenmerken tapwatersysteem

aantal woningbouw-eenheden aangesloten op systeem	*11*
warmtapwatersysteem ten behoeve van	*keuken en badruimte*
gemiddelde leidinglengte naar badruimte	*forfaitair*
gemiddelde leidinglengte naar aanrecht	*forfaitair*
inwendige diameter leiding naar aanrecht	*≤ 10 mm*
afgifterendement warmtapwater ($\eta_{W;em}$)	*0,742*

Kenmerken distributiesysteem tapwater

individuele afleverset	*ja*
afleverset aangesloten op	*HT*
distributierendement warmtapwater ($\eta_{W;dis}$)	*0,750*

Douchewarmteterugwinning

douchewarmteterugwinning	*nee*

Zonneboiler

zonneboiler	*nee*

Hulpenergie verwarming

hoofdcirculatiepomp aanwezig	*nee*
aanvullende circulatiepomp aanwezig	*nee*
afleverset met elektronica	*ja*

Aangesloten rekenzones

woning

Ventilatie

ventilatie 1

Ventilatiesysteem

ventilatiesysteem	*C. natuurlijke toevoer en mechanische afvoer*
systeemvariant	*C4b CO2-sturing indirect op toevoer per VR, zonder zonering*
luchtvolumestroomfactor voor warmte- en koudebehoefte (f_{sys})	*1,09*
correctiefactor regelsysteem voor warmte- en koudebehoefte (f_{reg})	*0,52*

Kenmerken ventilatiesysteem

werkelijk geïnstalleerde ventilatiecapaciteit bekend	*nee*
warmtepompboiler(s) in gebouw	*nee*
luchtdichtheidsklasse ventilatiekanalen	*onbekend*

Passieve koeling

max. benutting geïnstal. ventilatiecapaciteit voor koudebehoefte	*ja*
max. benutting geïnstal. spuicapaciteit voor koudebehoefte	*ja*

Kenmerken ventilatoren

type ventilatoren (vermogen forfaitair)	*gelijkstroom*

Aangesloten rekenzones

woning

Zonnestroom

zonnestroom 1

PVT systeem	*geen PVT systeem*
type zonnestroompaneel	*monokristallijn silicium (135 Wp/m2)*

Zonnestroom eigenschappen				
ventilatie	A_{PV} [m²]	oriëntatie	helling [°]	beschaduwing
niet geventileerd - op dak/gevel, geen spouw	93,00	Z	20	minimale belemmering

Resultaten

Jaarlijkse hoeveelheid primaire energie voor de energiefunctie		
verwarming (excl. hulpenergie)	$E_{H;P}$	31.776 MJ
hulpenergie		8.881 MJ
warmtapwater (excl. hulpenergie)	$E_{W;P}$	64.855 MJ
hulpenergie		0 MJ
koeling (excl. hulpenergie)	$E_{C;P}$	0 MJ
hulpenergie		0 MJ
zomercomfort	$E_{SC;P}$	1.494 MJ
ventilatoren	$E_{V;P}$	9.298 MJ
verlichting	$E_{L;P}$	55.296 MJ
geëxporteerde elektriciteit	$E_{P;exp;el}$	0 MJ
op eigen perceel opgewekte elektriciteit	$E_{P;pr;us;el}$	91.554 MJ

Oppervlakten		
totale gebruiksoppervlakte	$A_{g;tot}$	1.200,00 m²
totale verliesoppervlakte	A_{ls}	832,50 m²

Externe warmtelevering gebruik	
gebouwgebonden installaties	96.631 GJ

Elektriciteitsgebruik	
gebouwgebonden installaties	8.135 kWh
niet-gebouwgebonden apparatuur (stelpost)	33.638 kWh
op eigen perceel opgewekte elektriciteit	9.934 kWh
TOTAAL	31.839 kWh

CO_2-emissie		
CO_2-emissie	m_{co2}	7.458 kg

Energieprestatie		
specifieke energieprestatie	EP	67 MJ/m²
karakteristiek energiegebruik	E_{Ptot}	80.046 MJ
toelaatbaar karakteristiek energiegebruik	$E_{P;adm;tot;nb}$	325.058 MJ
energieprestatiecoëfficiënt	EPC	0,148 -
energieprestatiecoëfficiënt	EPC	0,15 -

In de berekening wordt gebruik gemaakt van het principe met een getrapte EPC eis conform Bouwbesluit 2012 artikel 5.2 lid 3.
Het gebouw voldoet aan de 2e trap eis inzake energieprestatie uit het Bouwbesluit 2012.
Bij deze berekening behoort tevens een berekening van de 1e trap eis.

Uniec 2.0 is gebaseerd op NEN 7120;2011 "Energieprestatie van gebouwen – bepalingsmethode" inclusief correctieblad C2 en NEN 8088-1 "Ventilatie en luchtdoorlatendheid van gebouwen - Bepalingsmethode voor de toevoerluchttemperatuur gecorrigeerde ventilatie- en infiltratieluchtvolumestromen voor energieprestatieberekeningen - Deel 1: Rekenmethode" inclusief correctieblad C1.

12.5.3 UNIEC CALCULATION (REUSED VENTILATION ENERGY CALCULATION) :

The following energy performance calculation was conducted to record the difference in ventilation demand if heat recovery is not applied.

Resultaten

Jaarlijkse hoeveelheid primaire energie voor de energiefunctie		
verwarming (excl. hulpenergie)	$E_{H;P}$	31.776 MJ
hulpenergie		8.881 MJ
warmtapwater (excl. hulpenergie)	$E_{W;P}$	64.855 MJ
hulpenergie		0 MJ
koeling (excl. hulpenergie)	$E_{C;P}$	0 MJ
hulpenergie		0 MJ
zomercomfort	$E_{SC;P}$	1.494 MJ
ventilatoren	$E_{V;P}$	9.298 MJ
verlichting	$E_{L;P}$	55.296 MJ
geëxporteerde elektriciteit	$E_{P;exp;el}$	0 MJ
op eigen perceel opgewekte elektriciteit	$E_{P;pr;us;el}$	91.554 MJ

Oppervlakten		
totale gebruiksoppervlakte	$A_{g;tot}$	1.200,00 m²
totale verliesoppervlakte	A_{ls}	832,50 m²

Externe warmtelevering gebruik		
gebouwgebonden installaties		96.631 GJ

Elektriciteitsgebruik		
gebouwgebonden installaties		8.135 kWh
niet-gebouwgebonden apparatuur (stelpost)		33.638 kWh
op eigen perceel opgewekte elektriciteit		9.934 kWh
TOTAAL		31.839 kWh

CO_2-emissie		
CO_2-emissie	m_{co2}	7.458 kg

Energieprestatie		
specifieke energieprestatie	EP	67 MJ/m²
karakteristiek energiegebruik	E_{Ptot}	80.046 MJ
toelaatbaar karakteristiek energiegebruik	$E_{P;adm;tot;nb}$	325.058 MJ
energieprestatiecoëfficiënt	EPC	0,148 -
energieprestatiecoëfficiënt	EPC	0,15 -

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Het gebouw voldoet aan de 2e trap eis inzake energieprestatie uit het Bouwbesluit 2012.
Bij deze berekening behoort tevens een berekening van de 1e trap eis.

Uniec 2.0 is gebaseerd op NEN 7120;2011 "Energieprestatie van gebouwen – bepalingsmethode" inclusief correctieblad C2 en NEN 8088-1 "Ventilatie en luchtdoorlatendheid van gebouwen - Bepalingsmethode voor de toevoerluchttemperatuur gecorrigeerde ventilatie- en infiltratieluchtvolumestromen voor energieprestatieberekeningen - Deel 1: Rekenmethode" inclusief correctieblad C1.

12.5.4 MPG CALCULATIONS :

1. Energy installations:

MRPI
milieu relevante product informatie

Rapportage Freetool MRPI Milieuprestatie Gebouw

In deze rapportage zijn de resultaten en de invoer opgenomen van de milieuprestatieberekening gebouw van Case 3. De resultaten zijn verdeeld naar de verplichte milieuprestatieberekening voor het bouwbesluit op basis van afdeling 5.2 en naar de MPG score. Tot slot is een verantwoording voor de berekening opgenomen.

Algemene gegevens

Naam project:	Case 3
Organisatie:	TU Delft
Gebruiksfunctie:	Woongebouw
Bvo:	1500 m2
Levensduur:	75 jaar
Datum rapportage:	02-05-2019

Resultaat bouwbesluit

In bijlage I is een overzicht opgenomen van de geselecteerde producten inclusief hoeveelheden en eventuele dimensies van het product. In de onderstaande tabel zijn de relevante resultaten opgenomen.

Milieu-impact	berekende waarde	eenheid
Uitputting abiotische grondstoffen (excl. fossiel)	0	kg Sb eq./ m2 BVO*jaar
Uitputting fossiele energiedragers	0,007	kg Sb eq./ m2 BVO*jaar
Klimaatverandering (100 jaar)	1,06	kg CO2 eq./ m2 BVO*jaar

De berekende resultaten zijn direct gekoppeld aan de in bijlage I opgenomen producten, een afwijkende materialisatie of productkeuze heeft invloed op de berekening. Indien in het verdere ontwerp- en bouwproces andere materiaalkeuzes worden gemaakt dient de milieuprestatie opnieuw berekend te worden.

Resultaat MPG-score

In bijlage I is een overzicht opgenomen van de geselecteerde producten inclusief hoeveelheden en eventuele dimensies van het product. De MPG-score van Case 3 is 0,14 € / m2 BVO. In de onderstaande tabel is dit resultaat weergegeven naar de verschillende bouwdelen.

Bouwdeel	Resultaat
Fundering	0%
Vloeren	0%
Draagconstructie	0%
Gevels	0%
Daken	0%
Installaties	100%
Inbouw	0%

Rapportage Freetool MRPI Milieuprestatie Gebouw

Bijlage I, invoer berekening

ongetoetst

getoetst

Fundering			
Vloeren			
Draagconstructie			
Gevels			
Daken			
Installaties			
Elektrische installatie			
Elektriciteitsopwekkingsystemen	PV,mono-Si; plat dak; incl. inverter+steun+kabels	93 m2	
Inbouw			