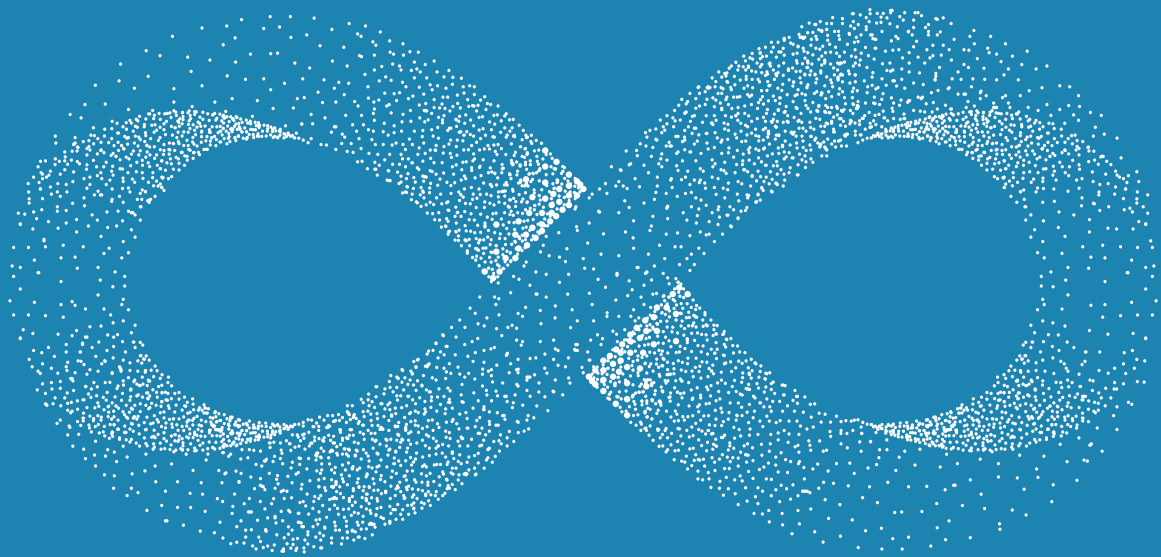


Guideline for Building Services Design

*inspired by
the Cradle to Cradle[®]
Concept*



ARUP

About Arup

Arup is the creative force at the heart of many of the world's most prominent projects in the built environment and across industry. We offer a broad range of professional services that combine to make a real difference to our clients and the communities in which we work. We are truly global. From 80 offices in 35 countries our 14,000 planners, designers, engineers and consultants deliver innovative projects across the world with creativity and passion. Founded in 1946 with an enduring set of values, our unique trust ownership fosters a distinctive culture and an intellectual independence that encourages collaborative working. This is reflected in everything we do, allowing us to develop meaningful ideas, help shape agendas and deliver results that frequently surpass the expectations of our clients. The people at Arup are driven to find a better way and to deliver better solutions for our clients.

We shape a better world.

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*“Eliminate the concept of waste,
Rely on natural energy flows,
Celebrate diversity”*

William McDonough, FAIA, INT. FRIBA
Co-Author of *Cradle to Cradle: Remaking the Way We Make Things*

NASA Sustainability Base
First Space Station on Earth
Moffett Field, California



William McDonough
Co-Author of
*Cradle to Cradle:
Remaking the Way
We Make Things*

Foreword

The book *Cradle to Cradle: Remaking the Way We Make Things*, which I wrote and co-authored with Michael Braungart in 2002, set out to define a new paradigm for looking at the world of things via the inspiration of nature; positing an optimistic way of thinking based on ideas of regeneration and cycles of material, energy, and biological flows, in which the world gets better through continuous improvement.

It was built upon precepts we espoused in *The Hannover Principles* a decade earlier:

*Eliminate the concept of waste,
Rely on natural energy flows,
Celebrate diversity*

Cradle to Cradle presented a new framework for human production and illustrated its concepts with real world examples; inviting everyone to be *Cradle to Cradle*-inspired. Over the intervening seventeen years, we and many others have continued to explore and refine the concepts. Ideas of design for human wellness, biophilia, and economic circularity, integrally linked in our texts, have since been taken up and expanded throughout the world. MBDC created the Cradle to Cradle Certified™ Products Program, which we launched in California in 2010 as the independent third-party, peer-reviewed, not-for-profit Cradle to Cradle Products Innovation Institute. C2CPII has certified more than 3,000 individual products. Meanwhile, my architecture firm, William McDonough + Partners, has designed building and planning projects globally which were inspired by Cradle to Cradle Design™.

The authors of this manual have undertaken a daunting challenge applying Cradle to Cradle Design principles to the various and detailed disciplines of building systems. The depth and intensity of this work is to be admired. There are not always easy answers and, as the authors point out, sometimes success in one realm may lead to compromise in another. The challenge is to achieve the right balance which results in the greatest benefit for human and ecological health and inspires principled progress.

This guideline is an important and bold first step, and one that will hopefully lead to much discussion and debate. I applaud the effort to bring rigor to the endeavor, and look forward to continued, elegant refinement.

I like to say “*The work of progress is, by definition, always a work in progress.*”

My companies and I work with this statement of intent:

“Our goal is a delightfully diverse, safe, healthy and just world – with clean air, water, soil and power – economically, equitably, ecologically and elegantly enjoyed.”



Circular Building, London
Engineer & Architect: Arup

Foreword



Carol Lemmens
Director,
Global Leader
Advisory Services,
Arup

At Arup, across all our professional disciplines, our focus is on the positive change design can make. We believe that existing practices regarding the materials, energy and waste produced cannot be sustained. As designers of some of the world’s most enduring buildings and infrastructure we know that leadership is needed to change the way we commission, procure, construct and operate the built environment.

We believe that embracing circular economy principles can enable Arup to tackle the complex nature of the built environment through multidisciplinary working, and that it can drive a shift towards more sustainable forms of economic growth, urban life and value creation. We are a knowledge partner of the Ellen MacArthur Foundation and a member of foundation’s CE100 business network, and the firm is already working on opportunities to embed circular economy principles in the built environment.

There is a close fit of the Cradle to Cradle concept and the circular economy principles – you could say the concepts complement each other. I am very pleased to see our teams preparing guidance on how these principles can be applied in the building services design; given that any successful circular design will require a holistic approach, I would encourage anyone working on the design of a circular building to review the proposals made in the initial chapters of each discipline, to consider how the team can deliver them together.



Beddington Zero Energy Development, Sutton
Engineer: Arup
Architect: Bill Dunster

Executive summary



Karsten Jurkait
Associate Director,
Advanced Building Engineering,
Arup

As outlined in Ove Arup’s key speech from 1970, our firm is striving for a positive impact on society at large in all its work; this is reflected in a constantly growing number of sustainable and community-focussed projects that the firm and its engineers delivered over the decades.

The Cradle to Cradle® framework resounds with our core values and our aim “to shape a better world”, and over the years we have been collaborating in a number of projects that aim to follow its principles.

During this work we found that there was a certain lack of definition of what Cradle to Cradle® means for building services design; this is mirrored in a lack of Cradle to Cradle Certified™ products, making it difficult for MEP engineers to deliver a C2C-inspired design.

With the creation and publication of this guide we are attempting to close this gap. Supported by the work of Johannes Stiglmaier as part of his Master thesis* and subsequent research commission, it provides proposed objectives for each of the building services disciplines, indicates what needs to be considered at each design stage, evaluates systems for their aptness for a C2C-inspired building, and identifies which materials could be suitable for such a building.

We would invite you to use this guide as a starting point when setting out to design C2C-inspired building services; it should give you a ‘head start’, but will not relieve you from having to investigate and decide upon the most appropriate solution for your project – every project has its own characteristics, the market is moving, and new products and technologies might have become available that suit your purpose better than those we had available when we wrote the guide.

When using the guide, please also keep in mind that we were not aiming for it to be “the ultimate reference for C2C” – we rather understand it as a first proposal for how C2C could look like in MEP design and would love to hear from you if you have comments regarding our propositions and findings, or suggestions for improvement.

That said, we hope you find the guide useful, and that it contributes to shaping a better world.

* Stiglmaier, Johannes, (2018, February 1), Impact of building services on recyclability, energy efficiency and life cycle analysis in building construction following the “Cradle to Cradle” design principles (Master Thesis). Technische Universität Berlin, Institut für Bauingenieurwesen, Berlin, Germany



Centre Pompidou, Paris
Engineer: Arup
Architect: Piano & Rogers

1. Introduction

The construction industry is quite resource-intensive, with a significant negative impact on the environment.¹ Traditionally its resources are consumed in a way that they cannot be recycled to an equivalent quality or returned to nature without a negative impact. Further challenges include energy use throughout the building lifecycle, water pollution, soil erosion and the impact of the constructed buildings on its users (eg indoor climate, social isolation).

The Cradle to Cradle (C2C) concept is attempting to address these challenges and turn them around: It is not only aiming to reduce the above effects but aims for buildings to actually make a positive contribution in the listed areas. The aim for buildings inspired by C2C is to avoid the generation of waste and creating a beneficial footprint: All materials used in construction and operation of the building become ‘nutrients’ for the technosphere or the biosphere, the composition of all components of the building is 100% known, and the corresponding materials considered healthy in their specific usage scenario. Buildings can thus function as material banks with the greatest possible positive impact in the areas of energy, water, air, economy and social inclusion.

This document is meant to serve as an initial guide for MEP designers who want to design their installations according to the C2C concept; it outlines how the C2C principles² can be applied in the individual disciplines of building services engineering, namely mechanical, electrical, and public health (MEP). For each discipline, minimum aims are proposed, and typical systems are assessed for their suitability for use in a C2C-inspired project; in every case an indication is given which aspects should be considered in each design phase (establishing the brief, system selection, system sizing, material selection) to apply the C2C principles.

At the time of writing, there are still no official guidelines for C2C-inspired MEP systems, so in many cases fundamental research had to be carried out to derive a first proposal for the application of the C2C concept to the various disciplines. The application of the C2C principles is also not yet widespread in the industry, so that enquiries regarding the suitability of products for C2C are often met with incomprehension. While quite a lot of research was carried out during the preparation of this guide, much still remains to be done, in particular on the materials side; the proposed criteria are also still rather a suggestion than established and widely accepted conditions. However, their application should contribute to the general C2C concept, and should help with achieving a wider use of the principle; the authors hope that this guide will contribute to further dissemination of the C2C concept among both designers and manufacturers.

1 Deilmann, Reichenbach, Krauß, & Gruhler, 2017, p. 8

2 McDonough & Braungart, 2002

1.1 Structure of the guide

The chapters of the guide follow the split of disciplines used in the German “Honorarordnung für Architekten und Ingenieure” (HOAI), which is not dissimilar to the split used in most other countries; they have been slightly re-structured to be able to illustrate the C2C principles:

Water systems

Gases and fuels

Heating systems

Ventilation systems

Cooling systems

Electrical installations

Extra-low voltage (ELV) systems

Vertical transport systems

Usage-specific / specialist systems

Building management / controls systems

Due to the particular importance the C2C concept is giving the choice of materials and the construction method (“design for disassembly”), additional chapters on “materials” and “construction methods” were created.

At the beginning of each chapter, the underlying objectives and criteria for the respective disciplines are defined; each chapter is then divided into the steps the HOAI foresees for the development of the design:

- establishing the brief, design criteria & boundary conditions (definition of the basic principles)
- system selection
- system sizing
- material selection
- construction methods

Each of the relevant sub-sections indicates what needs to be considered at each phase, in addition to a conventional design, and assesses systems and plant elements for their suitability for C2C-inspired projects. However, it should be kept in mind that considerations in one phase may affect other phases, so that when using the guide during the design, the guidelines of the entire chapter should be read and considered in each case.

The aim of the document is to determine the influence of C2C on the design and construction of all disciplines of the MEP systems, so even disciplines with a rather small influence on the building are covered.

From the point of view of the authors, there are no MEP-specific requirements in the C2C-inspired building process after system selection, design and material selection, so the tendering phase is not covered in this guideline (although for example social responsibility would have to be taken into account in this process to comply with the C2C principles).

The construction phase plays a fundamental role in implementing the C2C concept and is a theme in its own right, which warrants a separate guideline; all topics covered in the design would also be applicable in this phase but would have to be treated differently due to the temporary nature of the construction site. To limit the scope of this document, the construction phase is not considered in this document; it could be an addition in future revisions.

1.2 Approach of the guide

A first step in applying the C2C principles is to set objectives that each discipline has to achieve. The authors started by taking the C2C principles at face value and describing what each discipline would ultimately have to deliver to meet them; this resulted in a set of (intentionally utopian) ultimate C2C aims.

While these ultimate aims can probably not be achieved with the means currently available (or at all) or in a commercial environment, stating them offers a more profound understanding of the topic – it should be clear what C2C is aiming for – and hopefully helps the corresponding designer to understand the principles of the C2C design concept and mindset in the context of their work.

At the same time, the authors felt that only setting utopian aims would not be enough to guide designers to deliver a C2C-inspired design in real-life projects; to enable implementation, a set of realistically achievable minimum criteria were developed. These criteria can be considered initial steps toward the achievement of the long-term aims and would be the minimum required to consider a design for a specific discipline to be C2C-inspired.

Both the ultimate aims and the minimum aims are proposals designed to initiate discourse. In developing the criteria, the authors were guided by solutions that were technically feasible at the time the guide was prepared and sought a balance between the requirements of the C2C principle and the financial viability of the application. These boundary conditions may change over time (technical development, market development), so that a regular reassessment is recommended.

It should also be considered that having all disciplines meeting their respective minimum criteria could still be utopian; it is recommended that the design team identifies – together with the client – which applications would make the most sense and support the general vision for the building. As an example, an office building would probably want to concentrate on providing a healthy working environment (eg fresh and clean air), while a hotel might want to concentrate on water.

When preparing the guide, it was assumed that readers would be familiar with the design of MEP installations; it was also assumed that topics such as energy saving or reducing water consumption – which have been in the focus for years and on which there are a large number of guides – are sufficiently covered elsewhere and do not need to be dealt with in detail here.

Achieving the aims of a C2C-inspired design will often require developing holistic solutions that cross the traditional boundaries of disciplines or require new skills; in the field of MEP, this could be green facades, green roofs, biological air filtering, digital documentation, material passports or material knowledge. This guide deliberately focusses on the traditional duties of MEP engineers, only making reference to the scope of related specialists where this is relevant; it is assumed that the corresponding topics will be taken on by these specialists, and that they are covered in similar guides for the affected disciplines.

1.2.1 Definition of objectives and criteria

The C2C concept sets ‘positive balance’ objectives for buildings³; these go beyond a traditional ‘less bad’ mindset, aiming for buildings to have a positive impact on the environment in comparison to the empty building plot – for example, creating fresh air rather than just trying to reduce the air pollution caused by the building.

However, these general objectives have not yet been clearly defined or quantified, which makes applying the principle to real-life construction projects a challenge; this guide aims to address that by proposing concrete aims and criteria.

The proposed aims and criteria are authors’ interpretation of the C2C concept in the building context, developed in collaboration with further experts within Arup; in principle, other interpretations are also possible (eg a stricter application of the long-term objectives, or further compromises in the interest of reducing initial investments), but the authors consider their proposals to be a sensible and technically feasible balance between utopia and feasibility in the current environment of the construction industry.

For the development of the guideline, only criteria for the individual MEP disciplines (water, electricity etc.) were defined; interactions between the MEP disciplines or interactions with other disciplines (eg architecture or structural design) were not considered for the definition of the aims (but indications are given where these exist).

The following aim and criteria are defined for each discipline:

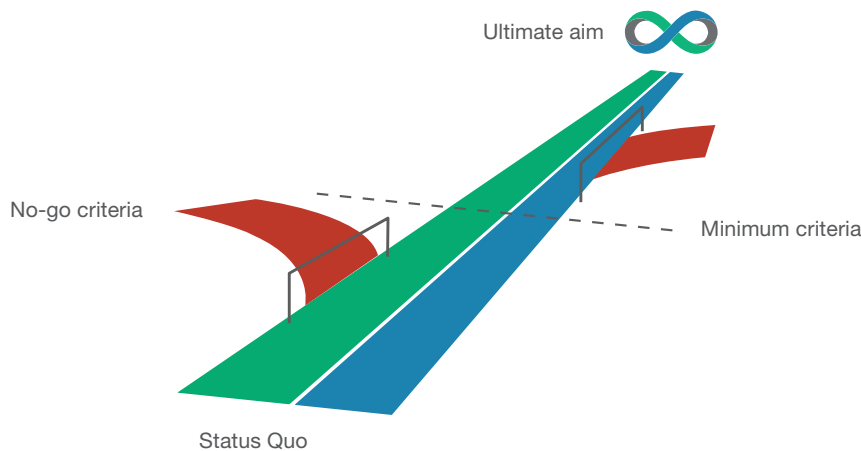


Image 1: C2C aim and criteria

C2C aim: Ultimate aim for the specific discipline, defining an overall long time aim for each discipline (which can be utopian). All other requirements are geared towards achieving this aim, with intermediate steps (minimum criteria) being defined for the route towards achieving this long-time aim.

C2C minimum criterion: Minimum requirements for achieving the C2C objectives so that the design for a specific discipline can be considered “C2C-inspired”. By reaching the minimum criterion, the ultimate goal has not yet been reached, but an active step in the right direction has been taken.

C2C no-go criterion: Different technologies or applications that are not compatible with C2C principles; a building in which they are applied or used cannot be considered “C2C-inspired”, even though the minimum criteria are met.

1.2.2 Assessment of compliance with the criteria

As C2C is a holistic approach, conflicting objectives can arise when trying to meet the criteria for different aspects (eg material use and energy consumption) or disciplines (eg use of façade surfaces to meet different criteria like daylight, greening, and solar energy).

In the individual chapters it is indicated which objectives are typically affected and which aspect should be given priority; however, quite often a decision on a case-by-case basis will be required, depending on the project-specific boundary conditions.

In principle, all criteria are regarded as equally important, so that a general prioritisation of the aims or criteria is not possible; prioritising individual cases is not the purpose of this guide. However, some general thoughts evolved from the evaluation of the most common cases:

As indicated above, C2C-inspired buildings should set a focus (eg “air” or “water”); this focus should be used to determine the priorities for individual measures.

If the energy consumed in the building is produced in a regenerative way, the minimisation of energy consumption is less important than the other criteria; the regenerative production of energy thus becomes a priority.

In the evaluation of materials and products, material health in the usage scenario and recyclability are to be regarded as the highest goals.

It is assumed that a component that has been designed to be recyclable and installed accordingly will continue to be used. This means that even if the primary cycle was very energy- or material-intensive, this can be offset by considering the corresponding consumption over the entire life cycle with multiple usage cycles of the material, where the later cycles would have a much lower energy and material input.

As a result, when C2C materials are used, their material consumption is secondary; they will be recycled or returned to the biosphere. In this context it can be helpful to imagine the building as a ‘material bank’ in which the materials are temporarily stored until they re-enter the cycle.

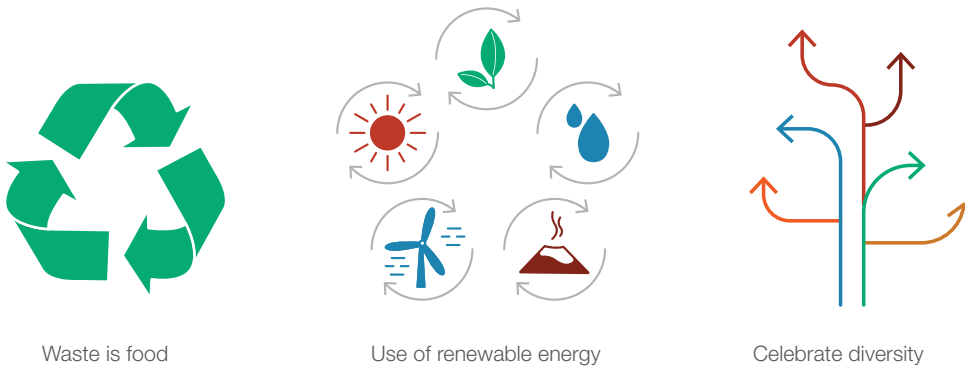
1.2.3 Boundaries and scope for the evaluation

The boundaries of the building plot and the impact of the materials on the health of the building occupants were the limits of the scope for the evaluation. Due to the complexity of such an analysis, the complete production cycle of individual materials was not evaluated.

In principle, the materials would have to be analysed along their entire creation chain; this includes several suppliers for each component and a large number of materials, starting with their origins as raw materials, so that such an analysis can take several years for a single product. Such a review could not be carried out as part of the investigations undertaken for this guide – it is considered the responsibility of the manufacturers, which can, for example, seek C2C certification for their products.

1.3 The C2C concept

To implement the C2C concept, it is important to understand its basic principles; the following paragraphs are intended to provide an initial overview.



The C2C concept was formulated by William McDonough and Michael Braungart.⁴

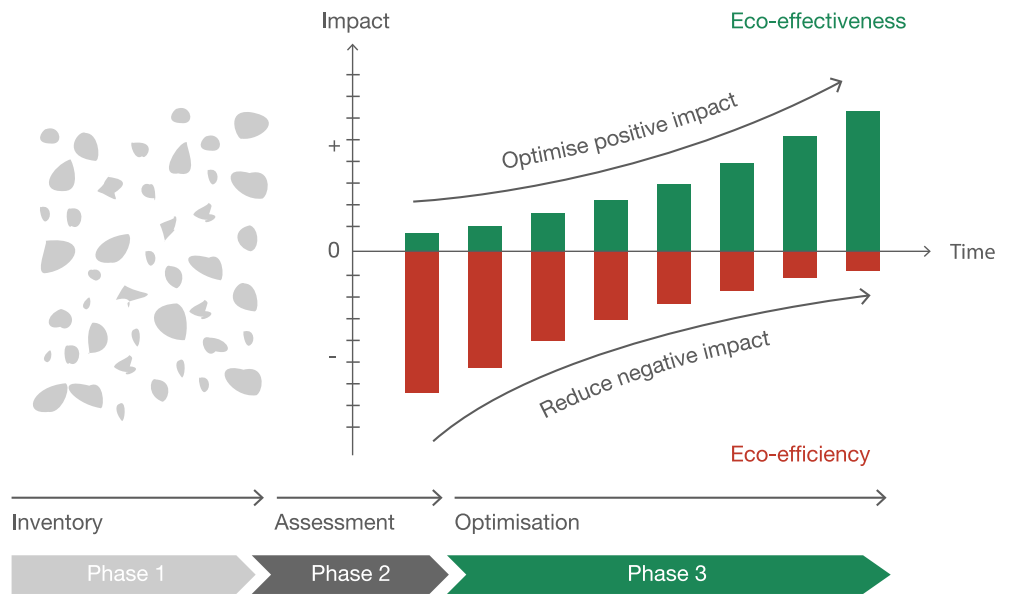
The C2C mindset addresses how environmental issues should be approached. The C2C principles are the guidelines that result from this mindset, and the C2C cycles describe the implementation of the principles.

1.3.1 The C2C mindset

In contrast to earlier concepts like eco-efficiency (“reduce and recycle”), the C2C concept is not only about reducing the negative footprint of humans in their ecosystem, but about creating a positive ecological footprint. This leads to a new perception of the human race having a beneficial footprint as opposed to a negative one.

To achieve this, a paradigm shift from simple eco-efficiency to so-called eco-effectiveness is needed, which is concerned with the type, usage scenario and quality of the materials or technologies, and not just with the quantity of a material or toxin. Figure 1 illustrates this shift.

Figure 1: The upcycle chart for continuous improvement, © 2010 MBDC, LLC



In addition to the eco-efficiency’s thinking of “reduce” and “recycle” to reduce the negative impact, the eco-effectiveness adds “re-think”, “re-use”, and “up-cycle” to actually offer a positive impact.

1.3.2 The C2C principles

To achieve the desired paradigm shift, the C2C design concept is inspired by nature and follows three main principles:

Principle 1: Waste is food – everything is a nutrient for something else; consequently, it must be possible to let all materials flow in continuous cycles in the so-called bio- or technosphere. This becomes a matter of using the right (ie healthy) materials for the respective usage scenario, ie not only using the wrong material as efficiently as possible.

All materials must be assessed and defined in terms of their impact on health in the specific usage scenario; this applies both to their manufacturing process and to their use during operation.

Waste is always accompanied by a loss in value of the material. To address this, C2C also promotes the quality of the materials and the conservation of their value, which also offers economic advantages.

While economic aspects cannot be used as a reason to ignore C2C criteria, the implementation of the C2C concept should not affect the economy; ideally, it even offers economic benefits. For this purpose, it makes sense to look for solutions that meet several C2C criteria at the same time.

Principle 2: Use of renewable energy – renewable energy is a basic requirement for a holistic and effective approach to recycling, and can be used for the operation of buildings and in the whole production process of materials and products.⁵

Principle 3: Celebrate diversity – as in nature, there can be a multitude of solutions and possibilities. Regional, cultural, creative or material differences should not only be tolerated but actually celebrated or consciously promoted.

The implementation of the C2C concept is also intended to improve the social environment, starting with the working conditions in the production of the materials and continuing with the social benefits of the product.

1.3.3 The C2C cycles

The C2C concept assumes that materials circulate continuously as ‘nutrients’, either in the so-called biosphere or the so-called technosphere. All material properties are known and all materials are assigned to one of the two spheres, which requires that all substances that make up the individual material or product are safe for their specific usage scenario and can be assigned to a future use case.

1.3.3.1 Biosphere

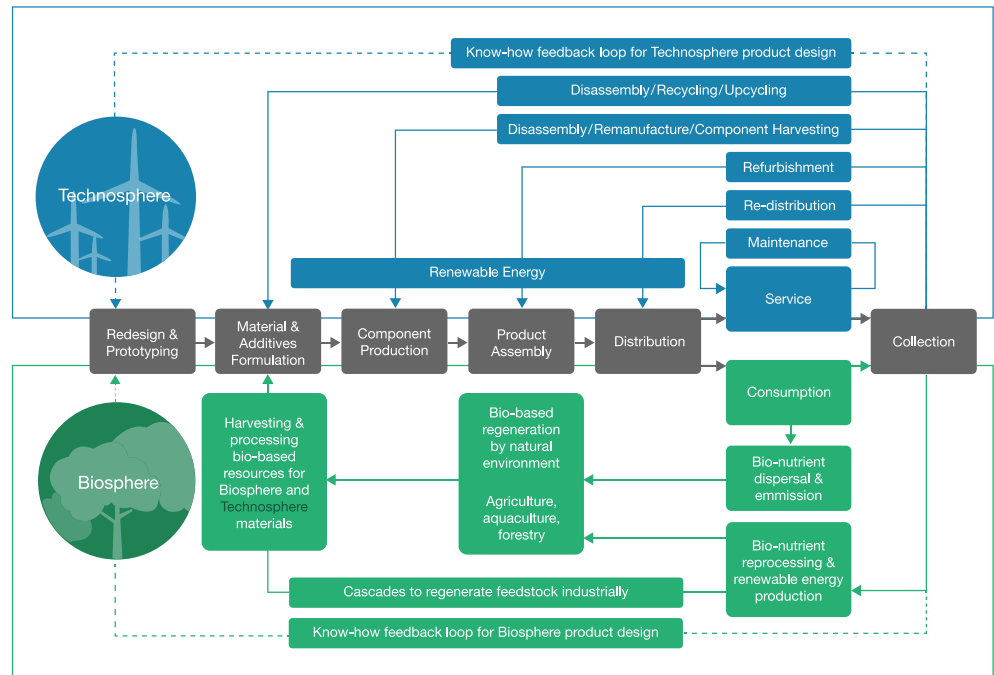
All materials that are consumed, ie wear out and end up in the environment (= cannot be re-used for another cycle), must be designed for the so-called biosphere. This means that they must be at least consumable (ie without harmful substances) and compostable to become a biological nutrient for new plants..

1.3.3.2 Technosphere

All materials that do not wear out in the respective usage scenario and are only used and not consumed must be designed for the so-called technosphere. This means that they must be non-harmful (in the use scenario), apt for disassembly, and reusable, to become raw materials for a new usage.

Figure 2 shows an overview of the C2C concept with the different stages in the cycles of the bio- and technosphere.

Figure 2: Overview Bio- and Technosphere (EPEA)



1.3.4 Cradle to Cradle Certified™

To assess compliance with the C2C criteria in the production of the materials used, *Cradle to Cradle Certified™* has been established as a certification system for materials. However, a product does not have to be *Cradle to Cradle Certified™* to comply with the C2C concept or to be used in a C2C-inspired building – certification is only one way to visualise the transition towards C2C, and simplifies material selection.

The assessment for *Cradle to Cradle Certified™* is carried out by the independent Cradle to Cradle Product Innovation Institute (C2CPII) in the USA. Table 1 shows the criteria used for the certification, which can also be used as an orientation to evaluate uncertified materials or products.

Material health	An inventory of product ingredients used throughout the supply chain is prepared and evaluated for impact on human and environmental health. There are different levels of certification, and the criteria for each level become more stringent, with the ultimate goal of eliminating all toxic and unidentified chemicals and becoming nutrients for a safe, continuous cycle.
Material re-utilisation	Products are designed either to biodegrade safely as a biological nutrient or to be recycled into new products as a technical nutrient. To reach the next certification level, more effort is required towards increasing the recovery of materials and keeping them in continuous cycles.
Renewable energy	At each certification level, the requirements for the grade of carbon neutrality and use of renewable energy for powering all operations is higher, with an ultimate goal of reaching 100%.
Water stewardship	Production processes are reviewed to see whether they regard water as a precious resource for all living things. To reach the next certification level, more effort is required towards cleaning effluents to reach drinking water standards.
Social fairness	The manufacturers have to treat all people and natural systems with respect. To reach the next certification level, more effort is required towards having a positive overall impact on mankind and the planet.

Table 1: Criteria for Cradle to Cradle Certified™ of the C2CPII

There are several levels for a *Cradle to Cradle Certified™* Product (Basic, Bronze, Silver, Gold and Platinum); certified products must re-certify and improve at regular intervals – otherwise their certificates expire.

The individual criteria for the certification levels are not covered here; further information can be found on the homepages of the C2CPII or of the *Cradle to Cradle Certified™* assessors, who support companies in the certification process (find assessors on www.c2ccertified.org/get-certified/find-an-assessor).

A list of all *Cradle to Cradle Certified™* products can be found on the homepage of the C2CPII, as well as a so-called “Banned-List”⁶, which contains all substances prohibited according to the *Cradle to Cradle Certified™* Products Program (www.c2ccertified.org).

Material health certificate: The C2CPII offers its own certification for the area of material health; it only looks at the criteria of material health, ignoring the other aspects. The certification levels are the same as those in the integrated *Cradle to Cradle Certified*[™] Product Standard.

As the Material Health Certificate only provides an evaluation of one criterion, a complete certificate is regarded as better (although products with a material health certificate should also be supported).

1.4 C2C in the built environment

In addition to the certification of products according to the systems mentioned above, the transformation of the built environment according to the principles of the C2C concept is an important step in the C2C mindset.

Buildings consist of materials and products, but their interaction has an overall impact on the environment that is not considered in their individual certifications; as living spaces, buildings also have a special importance as a system. In 1989, William McDonough formulated a vision for the built environment, “buildings like trees – cities like forests”⁷, in which buildings

- purify the air and the water,
- have a positive energy balance,
- increase biodiversity,
- make a positive contribution to the social environment, and
- promote the health of their users.

The “C2C Criteria for the built environment” defined by Braungart and Mulhall serve as the standard work for C2C-inspired-built environment⁸; these criteria have been developed further by Van de Westerloo, Halman and Dumisevic to describe them in more detail.⁹ The criteria are listed in the Table 2 on the following page, sorted according to the C2C principles. Since this guide deals specifically with MEP installations, the general C2C aims for the built environment are only presented as reference.

There is currently no C2C certification for entire buildings; only materials and products can be certified by the C2CPII to become *Cradle to Cradle Certified*TM. By evaluating the benefits or use of the building systems against C2C objectives, this guide has taken a first step towards facilitating a possible future C2C certification (or at least an assessment of the implementation of C2C aims) of buildings. However, the initial aim of the guide is to provide designers and developers with basic principles and food for thought on how the positive effect of buildings on their environment can be increased.

Foundational information on the C2C concept:

In the books:

Braungart and McDonough – *Cradle to Cradle – Remaking the way we make things*

Braungart and McDonough – *Cradle to Cradle – Remaking the way we make things*

Or on the internet:

C2C Product Innovation Institutes
www.c2ccertified.org

Cradle to Cradle e. V.
www.c2c-ev.de

Guide to C2C commercial sites
www.c2cbizz.com

⁷ Courtesy of William McDonough

⁸ Mulhall & Braungart, 2010

⁹ van der Westerloo, Halman, & Dumisevic, 2012

Table 2: C2C criteria for the built environment

C2C principles	Criteria and desired results	
Waste equals food	1. Define materials and their intended cycles	
	1.1 Materials and products can safely return in a biological or technological cycle, without quality loss	
	1.2 <i>Cradle to Cradle Certified</i> TM products and materials are applied in the building	
	1.3 Material contents come from renewable or recycled materials	
	1.4 The design and construction team assessed applied products and materials in the building based on their intended use and impact for its users and the surrounding	
	2. Integrate biomass production	
	2.1 More biomass, topsoil and clean water is generated by the building than before the development of the site.	
	3. Enhance air and climate quality	
	3.1 The outdoor air quality is improved by the building so the air becomes healthier than before development, and climate change gases are used to produce biomass	
	3.2 The indoor air quality is healthy and comfortable for occupants and users.	
	4. Enhance water quality	
	4.1 The quality of water is improved by the building and healthier than before it entered the building.	
	Use of renewable energy	5. Integrate renewable energy
		5.1 More renewable energy is generated by the building and its site than the building consumes
		5.2 Energy-efficiency is used to introduce renewable energy rather than reducing fossil fuels
		5.3 Exergy is used as a way to guide energy effectiveness
5.4 Innovative techniques to produce renewable energy are integrated		
5.5 A monitoring system that measures the energy consumption and production is used.		

C2C principles	Criteria and desired results
Celebrate diversity	6. Biodiversity 6.1 Biodiversity is increased by the building.
	7. Conceptual diversity 7.1 Innovative elements of the building are beneficial for the wellbeing of occupants and the environment.
Further criteria	8. Organize reverse logistics 8.1 Supply and discharge of defined materials and products is organised.
	9. Design for (dis)assembly 9.1 A plan to deconstruct building elements, products or materials without demolition waste is made 9.2 The building can be adapted without demolition waste.
	10. Define intended use periods 10.1 Intended use periods of the building, products and materials are defined.
	11. Enhance environmental qualities 11.1 The building improves the quality of the building surrounding 11.2 The quality of the top soil is improved by the building (including green roofs).

2. C2C in buildings services

In the following chapters, the C2C criteria for the built environment according to Braungart and Mulhall¹⁰ are applied to the various disciplines of MEP installations. Table 3 gives an overview of the C2C aims and criteria of the different disciplines; the objectives and criteria are explained in more detail in the individual chapters.

Table 3: Overview of C2C aims and criteria for building energy systems

Range	C2C aim(s)	Meaning	C2C criteria
Water systems	Water and nutrient positive	Building cleans water	Minimum: Water balance, water treatment, measurement of waste water quality No-Go: Water pollution
Gases and fuels	No hot combustion and using fuels produced of fuels	Using only fuels produced on site, avoiding hot combustion technology	Minimum: Exhaust gas filtration, no air pollution No-Go: Fossil fuels, energy crops
Heating systems	100% renewable heat coverage	Building's heat demand supplied completely from renewable energy	Minimum: Own regenerative heat production No-Go: Fossil heat generation
Ventilation systems	Positive oxygen balance and indoor environment contributing to wellbeing	Building produces more oxygen than it consumes; pollutants are filtered, highest indoor air standards are reached	Minimum: Healthy indoor air and neutral exhaust air No-Go: Harmful exhaust air and unhealthy indoor air
Cooling systems	No unique C2C aim	Support for C2C objectives in other areas	Minimum: Optimisation of cooling demand and material use No-Go: Use of energy generated from fossil fuels
Electrical installations	Positive electrical energy balance	Building's electrical energy demand is supplied completely from renewable energy, with an annual surplus	Minimum: Own renewable electricity production No-Go: Electric energy from fossil fuels

Range	C2C aim(s)	Meaning	C2C criteria
Extra-low voltage (ELV) systems	No unique C2C aim	Applications and materials correspond to C2C principles, where applicable support of C2C objectives of other areas	Minimum: Materials & construction methods follow C2C criteria No-Go: See "Materials"
Vertical transport systems	No unique C2C aim	Applications and materials correspond to C2C principles, support of C2C objectives of other areas	Minimum: Optimisation of energy & material use No-Go: See "Materials"
Usage-specific / specialist systems	No unique C2C aim	Applications and materials correspond to C2C principle support of C2C objectives of other disciplines	Minimum: Optimisation of energy & material use No-Go: See "Materials"
Building management / controls systems	No unique C2C aim	Applications and materials correspond to C2C principle support of C2C objectives of other disciplines	Minimum: Energy monitoring; optimisation of energy & material use No-Go: See "Materials"
Material	100% C2C materials	Only use of material proven to be apt for usage scenario, and documented in material passports	Minimum: Creation of a material passport for all systems No-Go: Use of Materials on the Banned List of the C2CPII
Construction methods	100% apt for disassembly	All materials used in the MEP systems designed according to DfD principles	Minimum: Application of the basic principles of "Design for Disassembly" No-Go: Connections that do not allow separation of materials by material type

3. Water systems

3.1 Aims and evaluation criteria

3.1.1 Overview

C2C aim	Water- and nutrient-positive
C2C minimum criteria	Water balance, water treatment, monitoring waste water quality
C2C no-go criteria	Water pollution
C2C material criteria	See chapter 13
C2C construction methods	See chapter 14

3.1.2 Explanation

Water positive means that the building has a positive influence on the water cycle - the water quality at the site should be better with the building than without.¹¹

The focus of the C2C concept is on improving the quality of the water, not simply reducing consumption.

When applying the criterion of having a positive influence on the water cycle, it is important to understand that according to the C2C concept, “better” does not necessarily mean “cleaner” in the traditional sense – biological waste products can be nutrients for plants, which from a C2C point of view does not reduce the water content quality compared to pure drinking water (as long as these nutrients are also used and are not over-fertilising the biosphere). However, drinking water has a higher quality of use, as it can be used for more applications.

To meet the criterion of water pollution, the contamination of waste water or rainwater with harmful substances (the criterion “water pollution” mentioned above) must be avoided or reduced.

To determine whether the building has a positive influence, the status quo of the site is to be established as a boundary condition: What is the amount of precipitation that falls annually on the property, and in which quality? This should then be regarded as a baseline and compared with the balance of the site with building (consumption, waste water quality etc.). When using groundwater (eg wells), the flow rate and water quality would also have to be measured.

While the quality of the water leaving the building is crucial for the C2C assessment, a balance of the amount of water entering and leaving the building must also be established; this balance should be as neutral as possible – ideally, the building will supply itself with the amount of rain falling on the site, although this will not always be possible depending on location (climate) and use (water consumption).

Water positivity could therefore also be achieved by producing more usable water at the site than without buildings, eg by the use of grey water treatment; however, it should be noted that the pollution of the waste water with harmful substances cannot be balanced out by producing more usable water, so avoidance and treatment must be given priority.

During operation, measurements of the waste water quality leaving the building must be carried out and compared with the precipitation water quality without the building, to be able to assess necessary measures.

Nutrient positive means that the building has a positive influence on the production of biomass and topsoil. In a C2C-inspired building, biological nutrients bound in urine, faeces or biological waste should be recovered and recycled as far as possible. Systems should be planned to enable these nutrient cycles.

Figure 3 shows an overview of the components of wastewater and water systems in a C2C-inspired building.

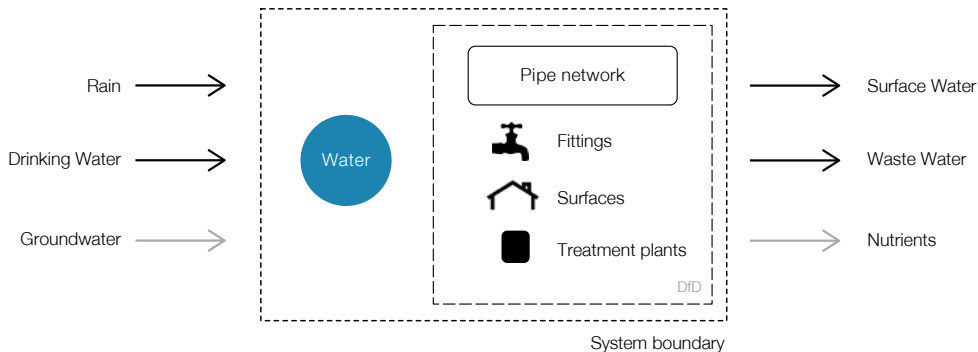


Figure 3: Overview water system in a C2C-inspired building

3.2 Means of implementation

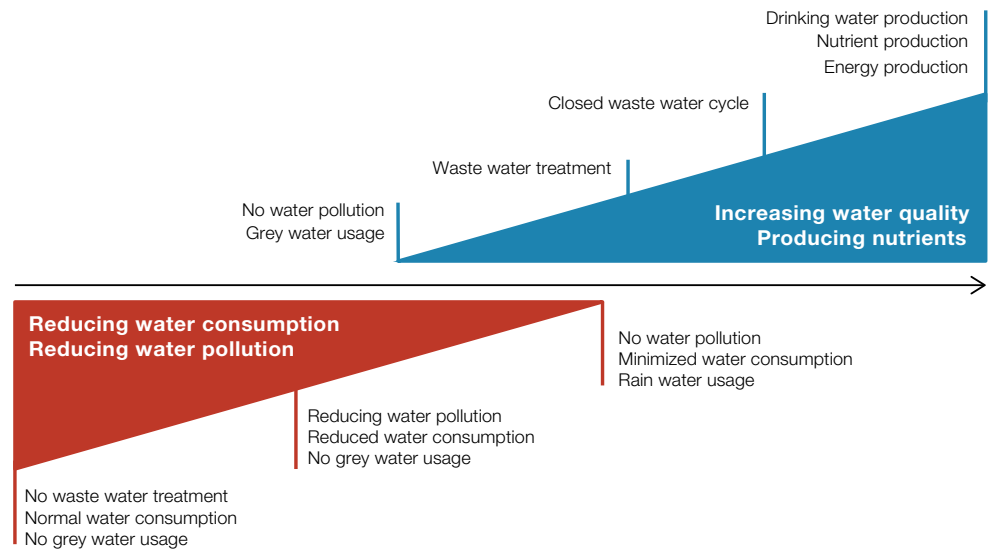
To improve the water quality, both avoiding contamination and filtration/treatment of the water can be considered – the quality of the water when it leaves the building/site is the critical factor from a C2C point of view.

To achieve a quantitatively neutral water balance, both measures to reduce consumption and technologies to provide drinking water can be considered.

The re-use of water on the site reduces the onus on treating water leaving the site, and can therefore be considered a further possible means of achieving the C2C objectives.

Figure 4 shows a classification of the various measures and steps in the field of water.

Figure 4: Roadmap for water systems in C2C-inspired buildings



3.3 Design criteria & boundary conditions

The first step in the development of the brief is to determine what amount of annual precipitation the site experiences, and in what quality. While the former will be statistically recorded in most cases, the quality is like to be usually more difficult to determine; a rainwater collection (and subsequent laboratory analysis) will probably have to be organised during the design phase to obtain a reference value.

When groundwater is used, the quality of the water must also be determined, together with the annual flow rate that flows through the property.

Substances that enter the water during operation of the building will need to be analysed, the risks for water pollution (eg by surfaces coming into contact with the water, cleaning agents, waste materials from the use of the building) will have to be identified, and the quality up to which the waste water will need be cleaned or kept clean of them will have to be established.

Substances	Grey water contains	Max. values for grey water	Black water contains ¹²	Max. values for drinking water ¹³
Lead	-	-	0.02...0.05 mg/(E*d)	0.01 mg/l
Copper	-	-	1.2...1.8 mg/(E*d)	2.0 mg/l
Nitrite	-	-	-	0.50 mg/l
Sodium	-	-	-	200 mg/l
Coliform bacteria	10 ² ...10 ⁶ per ml ¹⁴	< 100 per ml	10 ⁴ ...10 ⁷ per ml	0 per 100 ml
Escherichia coliform bacteria	10 ¹ ...10 ⁵ per ml	< 10 per ml	10 ⁴ ...10 ⁷ per ml	-
BSB7	-	5 mg/l	-	-
BSB5	16.7 g/(E*d)	-	21...29 g/(E*d)	-
Phosphor	0.2 g/(E*d)	-	0.9...3.3 g/(E*d)	-
Nitrogen	0.8 g/(E*d)	-	9...19 g/(E*d)	50 mg/l
Fluoride	-	-	-	1.5 mg/l

Table 4: Overview of contents of important substances in drinking, grey and black water and their maximum values

¹² Herbst, 2008, p. 43

¹³ Bundesministerium für Gesundheit, 2001

¹⁴ Fachvereinigung Betriebs- und Regenwassernutzung e.V. (fbr), 04.05, p. 12

The guidelines of the Drinking Water Ordinance, the Wastewater Ordinance, and the list of priority substances¹⁵ can serve as an orientation for the required water quality. Substances that are on the C2C banned list or are classified as problematic in the certification are not allowed to get into the water (waste water or drinking water); alternatively, they must be removed again. A list of problematic substances is not currently published by the C2CPII, so it cannot be used for consideration; should it be made available in the future, these substances would also have to be taken into account.

A minimum requirement is the filtration of waste water from surfactants (residues from soaps, detergents, etc.).

It must also be defined to what extent self-sufficiency of the water cycle is aimed for. For example, it should be stated how much rainwater or greywater is to be used to achieve the desired balance (and what water quality is required for this), how much water is taken from the cycle, and/or how much water should be treated on the site itself.

The saving potential by rainwater is obviously depending on the precipitation rates; in Germany, a realistic goal is to reduce drinking water consumption by 50% in single-family homes.¹⁶ Grey water recycling can also save drinking water. According to manufacturers, a 100% supply of single-family houses is possible by treating rainwater to drinking water. According to Wohnwagon GmbH a water self-sufficient office building is also possible by adjusting the size of the used components.¹⁷

If water quality is to be improved through nutrient use, how these nutrients are used (ideally on the site) is to be stated in the brief, too. A minimum requirement for the usable quantity cannot be defined from a C2C point of view – ideally all black water flows are used, but it only makes sense to extract as many nutrients from the wastewater as are usable on the site; there is currently no structure available for a retention or economic use of the extracted substances.

The desired economy in the implementation of the C2C aim may result in further design values, eg efficiency of water use, optimisation of space uptake for plant rooms, etc.

¹⁵ Europäisches Parlament und der Rat der Europäischen Union, 2013

¹⁶ FBR e. V., 2017

¹⁷ Wohnwagon, after E-Mail contact 13.9.18

3.4 System selection

When selecting a system, it must be established by which systems the desired positive impact on the water cycle is to be achieved. It is to be clarified what is planned to achieve the water quality and water balance aims; systems would typically fall under

- Avoidance of water pollution
- Water treatment
- Utilisation of nutrients
- Reduction of water consumption
- Water re-use
- Water production

C2C-inspired drinking and waste water distribution within the building basically has the same requirements as in conventional building projects; they may differ in the choice of materials and a requirement for the most energy-efficient distribution possible.

3.4.1 Avoidance of water pollution

Most of the water entering the building is not contaminated by building services systems but by the building use; this cannot be influenced by the system selection of the MEP installations and is therefore not covered in this guide. However, avoiding contamination should be part of the building's C2C concept; contamination also influences the design of the MEP installations for water treatment, and the development of a corresponding concept should be actively pursued by the MEP designer.

One possibility of influencing water pollution is the degree of hardness of the drinking water; a lower degree of hardness requires less detergent during washing, so that a softening system can be considered where particularly hard water is supplied (water hardness in the "hard" range starts from 14° dH^{18,19}), depending on the use of the building.

Another possibility is the use of urine-separation toilets. This technology can make the nutrient management of the building easier but has an effect on the operation of the building (eg on cleaning and maintenance costs) and on user acceptance, so it should be explicitly clarified with the building owners and users before adopting it.

Another possible source of contamination is the contact of rainwater with surfaces of the building envelope or the sealed external surfaces;²⁰ this aspect is the responsibility of the architect and is therefore also not considered part of the scope of this document, but should be actively flagged and followed up by the MEP designer.

Water can also be polluted by MEP systems; this can be by contact of the water with the materials of the water distribution systems, by chemical treatment in the water systems, and by unforeseen discharge of harmful materials into the water system (eg leakage of glycol on drained surfaces).

18 Alfiltra GmbH, 2013

19 Hillenbrand & Böhm, 2004

20 Burkhardt, 2015

Since the latter is already covered in the relevant legislation (Drinking Water Ordinance, Water Resources Act) and must therefore be taken into account in the design anyway, this is not discussed here; the former is dealt with in the subchapter 3.6 “Material selection”

3.4.2 Water treatment

Rainwater: If the roofs, facades and all other external surfaces that come into contact with the falling rainwater are optimised according to C2C and thus do not cause a reduction in the quality of the water content, then in theory no rainwater treatment would initially be necessary to improve the water quality; treatment this is only necessary because the rainwater commonly is contaminated with harmful substances such as (bacteria, viruses, parasites, and fine dust).

The degree of required filtering depends on the use of rainwater. For watering the garden, only a mechanical filter and a resting basin (storage tank) are necessary.²¹ If the rainwater is used to operate a washing machine, a fine filter is required; this is achieved in a similar way to greywater treatment²²), utilising membrane or nanofiltration (offered by companies such as Intewa Aqualoop Tap Comfort or Urspring Home, StormSaver, WaterScan, etc.). More detailed information is provided under “Drinking water”.

If a percolation is planned, the rainwater must also be cleaned; the type of filtration depends on the condition of the collecting surface (eg roof, parking lot) and the corresponding degree of contamination – possible are physical (sedimentation), chemical (precipitation or adsorption) and mechanical filters.

A clear statement on the suitability of the various filter technologies according to C2C criteria cannot be made at present, due to the lack of information provided by the manufacturers. A basic principle would be “less is more”, ie the water should be treated with as little filtration as possible; since the degree of pollution determines the use, the rainwater should only be treated as far as the use requires.

Grey water: In contrast to rainwater, grey water must be assumed to be contaminated; however, it must be established in each case whether suitable operational measures can be taken to prevent the water from being contaminated by harmful substances.

Grey water can be divided into the categories lightly and severely polluted (according to EN 12056-1); it must be clarified which category is to be used in the building. Furthermore, it must be decided whether the grey water is to be treated to process water or drinking water quality. According to the C2C principle, the aim should be to use and treat all the grey water; whether this is done as grey water, process water or drinking water is initially not decisive - this must also be decided for the respective project taking economic aspects into account.

In any case, surfactants and (if necessary) grease (eg in kitchens) and other impurities should be removed from the water²³, so that water treatment must always be provided for C2C-inspired buildings; if the water is used further in the building (see “Reduction of water consumption” or “Water production”), additional treatment (ultrafiltration or UV treatment) may be necessary.

21 Fachvereinigung Betriebs- und Regenwassernutzung e.V. (fbr), 2017, p. 4

22 Herbst, 2008, p. 70

23 Herbst, 2008, p. 45

There are biological and technical treatment methods for the treatment of process water; an overview of use and quality requirements can be found in the dissertation of Herbst, p. 73 ff.²⁴. The following tables give an overview of the procedures mentioned there.

Type of treatment		Cleaning by	Aptness for C2C
Ponds		Bacteria in the root area	Suitable
Overgrown soil filters	Horizontal or vertical flow through	Bacteria in the root area	Suitable

Table 5: Overview of natural treatment of grey water

Type of treatments	Type of cleaning	Often in connection with	Aptness for C2C
Biofilm processes			
Rotary discs trickling filter	Cleaning by microorganisms	UV disinfection (also suitable for C2C)	suitable (for natural substrates; for other fillers C2C-materiality must be observed)*
Fluidised bed reactors	Cleaning by microorganisms	UV disinfection (also suitable for C2C)	suitable (for natural substrates; for other fillers C2C-materiality must be observed)*
SBR reactor (similar to flow-through process)	Cleaning by microorganisms		suitable
Membrane activation process			
Ultrafiltration membrane	Filtering by small pore width of the membrane	UV disinfection (also suitable for C2C)	C2C suitability still to be clarified

Table 6: Overview technical treatment of grey water

* Information about carrier material^{25,26}

In practice, mostly combinations of biological and technical (membrane) processes are used in a membrane bioreactor (MBR reactor); their filtration rates meet the EU Bathing Water Directive and also filter phosphates and surfactants from grey water.

The microorganism used in all processes remove surfactants from the grey water.²⁷ None of the systems above for greywater treatment includes phosphorus recovery; this is currently only offered as an option for small sewage treatment plants (P-Elimination Modules), mostly by chemical precipitation with the precipitant poly-aluminium chloride (eg Graf GmbH P+Modul). A C2C suitability of this treatment is still to be investigated and depends on the composition of the precipitant, which is classified as slightly hazardous to water (water hazard class 1).

²⁴ Herbst, 2008, p. 73

²⁵ Universität Bremen Institut für Umweltverfahrenstechnik, n.d.

²⁶ DIN e. V., 2007

²⁷ Wallbaum & Prof. Dr.-Ing. Weining, 2012, p. 2

There are also biological systems for phosphorus elimination (polyphosphate accumulating organisms in an anaerobic tank), but these are not yet used in connection with greywater recycling. The lower phosphorus concentration in the grey water and the sensitivity of the biological filtration processes can be cited as causes here.

With the above-mentioned treatment methods, no residues remain in the water, depending on contamination and technology, but waste will still be produced; priority should therefore be given to reducing the amount of pollutants entering the water, which makes costly cleaning steps obsolete.

So far, chemical-physical techniques are rarely being used in buildings; they are employed to filter trace substances (eg drug residues) from the water, which would in principle be a welcome improvement of water quality. A statement as to whether these technologies comply with C2C principles could not be clarified during the preparation of the guideline; however, in general they are compliant with current codes and regulations (eg Drinking Water Ordinance) and can therefore presumably be regarded as suitable for C2C-inspired buildings.

The research carried out during the preparation of this guide suggest that the technologies mentioned above are suitable for C2C-inspired buildings, as long as the material requirements (especially for the materials the water is exposed to) is met. If the use of UV disinfection is suitable for C2C-inspired buildings could not be clarified; the treatment removes both harmful and beneficial bacteria, so it is not clear if the overall effect is positive in the spirit of C2C.

According to C2C criteria, natural treatments are to be favoured. Due to the current introduction of trace substances (eg drug residues, microplastic, etc.) into the wastewater, additional technical treatment is often required, as these substances are harmful to plants.

It is crucial that C2C-inspired buildings provide a treatment / removal of contaminants in the waste water, and that the corresponding equipment meets the C2C criteria (material, energy consumption) as far as possible. However, it may be necessary to take into account that biological processes (such as pond systems or soil filters) allow filtering, but make it difficult to continue to use the water in the building.

As described in the previous section on rainwater re-use, it is critical to consider what the re-re-use water is being used for – this will determine the level of treatment required. It is equally critical to consider the treatment processes for each type of waste discharge; depending on the building, it may be practical to have separate systems for

1. baths and showers,
2. wash basins, kitchen sinks and white goods, and
3. black water fitments.

This is because the largest water users in residential properties are baths and showers; they generally have the least contaminants, as they use much larger volumes of water. Wash basins would see similar types of contaminants entering the waste water prior to treatment, but the contaminants would be far more concentrated, meaning greater levels of treatment are needed.

Black water: Depending on the use of the building, different contaminations of the black water can be assumed. Industrial pollution is considered a special case and is not considered in this guide; the same applies to contamination by medicines – only biological contaminants such as faeces and kitchen waste were considered.

As already explained under “Aims and criteria”, contamination by biological waste materials should not initially be regarded as a reduction in quality but possibly even as an improvement; however, this is only the case if the biological waste materials are actually used.

For this purpose, black water treatment should be provided in C2C-inspired buildings, for which suitable small sewage treatment plants are already available on the market.

Although the municipal black water treatment in sewage treatment plants is working technically correct, in most cases the systems are not C2C-compliant where it comes to nutrient utilisation: Half of the sewage sludge is actually burned²⁸ (partly biogas is produced in advance, partly phosphorus separation is carried out); as a result, the natural raw materials contained in the sewage are lost to the biological cycle.

A pure discharge of black water into the sewerage system is therefore not acceptable for a C2C-inspired building (unless use of the nutrients in the corresponding sewage treatment plant can be proven); some use in the building should therefore be provided for. If the sewage sludge cannot be used completely in the building, partial use of the black water (eg only from one riser) would be conceivable.

Separating the black water into yellow water (urine) and brown water by separating toilets facilitates the extraction of nutrients.

Depending on the intended use and treatment, separate piping systems for grey, yellow and black water will have to be provided in the building.

Drinking water: There are currently four systems for treating filtered grey water (process water) or well water to drinking water quality: Ultrafiltration, reverse osmosis, chlorine treatment and UV disinfection.

Chlorine treatment is ruled out due to the harmful effect of chlorine. UV disinfection is often used as an additional step in combination with an ultrafiltration or reverse osmosis plant. Which of the remaining processing technologies should be preferred according to C2C criteria could not be finally clarified during the preparation of the guideline; the main reason is that for both systems the membrane material is not yet optimised according to C2C criteria. A decision will have to be taken on a case-by-case basis, following factors like cost efficiency, used space, and water quality requirements.

3.4.3 Utilisation of nutrients

The nutrients produced by a C2C-inspired building and its uses should be used locally wherever possible. The design should consider which portion of the nutrients can be used meaningfully locally and which can be delivered as surplus to a central system, neighbouring buildings or companies. Where the nutrients cannot be used, a treatment does not make sense – in this case such a treatment can be omitted.

For better use of nutrients, black water should be collected separately from grey water, with the least possible addition of water and/or supported by separate collection of yellow water (urine) by separating toilets or urinals.

A complete black water cycle – ie including the use of nutrients – within the building is currently difficult to implement; for this purpose, a use of the sewage sludge on site has to be found. First projects like the Jenfelder Au in Hamburg (Hamburg Water Cycle) or the “Komplett” project²⁹ are already heading in this direction, but their concepts will not be feasible everywhere.

Humus: The nutrients collected or filtered out in the wastewater or by a separation toilet can be composted and used as humus. There are various systems for composting (eg vermicompost³⁰); composting plants are not part of the water cycle and would have to be coordinated with the responsible designer (eg landscape designer).

Generation of biogas: The collected solids from the waste water – possibly together with food residues and similar waste – can be fed into a biogas plant and thus generate gas. More detailed information on gas plants can be found in chapter 4. The “Hamburg Water Cycle” in the Jenfelder Au district is an example of such a project.

3.4.4 Reduction of water consumption

The reduction of water consumption supports the achievement of a neutral water balance and reduces the costs and size of installations to increase water quality.

Measures to reduce water consumption are already being adequately addressed elsewhere; only their suitability in terms of the C2C principle is discussed here.

In addition to the efficient operation of toilets, fittings, etc., the behaviour of users has a considerable influence on water consumption. The latter is not part of this guide, but users should be informed about measures and rules of conduct for the most effective operation.

In the following, some technical measures are evaluated regarding their C2C suitability.

Waterless urinals: In addition to reducing water use, the lower material costs for piping and separating urine and water (better treatment potential) are positive, which makes the system suitable in principle for C2C-inspired buildings; at present, however, the materials used are not yet C2C-compliant (see subchapter 3.6.6 “Waterless urinals” in the chapter 3.6 “Material selection”), so that the selection of a specific, C2C-suitable product will be decisive.

Low-flow toilets: So-called low-flow toilets, which reduce the water flow per flush, should in principle be supported from a C2C perspective. The lower water consumption simplifies the treatment of black water because the systems are less used to capacity; in addition, the greywater or rainwater consumption of the flushing water is reduced (and thus the cost of the corresponding treatment), or less drinking water is polluted.

However, it should be taken into account that low-flow systems are more susceptible to blockages and thus present a risk of lower user acceptance; a combination with vacuum toilet systems (see below) may be advisable.

Vacuum toilets: By using vacuum systems, water consumption can be reduced (to only approx. 1 l per flush).³¹ The reduced use of water makes it easier to use the nutrients of brown or black water.

To install a vacuum system, special vacuum toilets and a vacuum station (including vacuum pump, vacuum tank, waste water pumps and control cabinet) are required. Currently there are several systems on the market, with different technical complexity and differing components.

A final statement as to which system is best suited according to C2C criteria cannot be made at present; in principle, however, the most compact and efficient system possible should be preferred (eg the vacuum system JETS™, which does not use a tank but only a pump³²), and the active elements (pumps) should be supplied with regenerative energy.

At the time this guide was prepared, there were no *Cradle to Cradle Certified™* vacuum systems on the market, nor systems manufactured according to similar criteria.

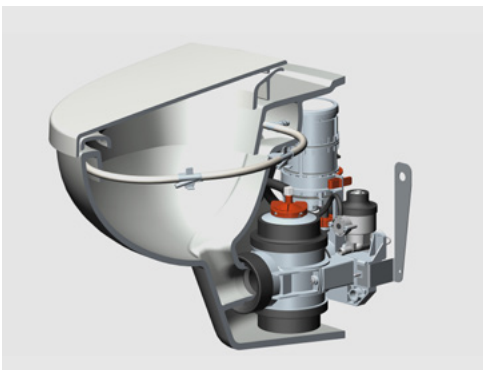


Image 3 (left): Closet of vacuum toilet system.

Image 4 (right): Plant room of vacuum toilet system.

31 Fraunhofer ISI, 2010, p. 104

32 Steinbach Ingenieurtechnik, n.d., p. 4

Faucets and urinals with infrared sensors: The main purpose of faucets and urinals with infrared sensors is to save water; they also offer improved hygiene, which can be an issue in public baths, for example (although this can also be addressed by using copper fittings^{33,34}).

These benefits are achieved with increased technical complexity – in addition to the inlets and outlets for the water, electrical lines must be installed, and the electronic components consume electricity during operation. In addition, the electronic components are not suitable for C2C (low recyclability of the materials used) at the time of preparation of this guide.

In balance, faucets and urinals with infrared sensors are considered apt for C2C-inspired buildings, with their benefits outweighing their disadvantages; care should be taken in the material selection of the required components – see also in chapter Electrical Installations on [“8.6 Material selection”](#).

Pressure reduction: Whether a pressure reduction in the water system makes sense or not can be decided according to conventional design criteria; from a C2C point of view there is no preference.

Aerators: In their function as water savers and oxygenisers, aerators indirectly help to achieve the C2C aims. Their suitability for C2C depends on the material used; stainless steel components are currently the preferred choice, because due to the lack of transparency among manufacturers the suitability of plastic components cannot be assessed.

3.4.5 Re-use

The longer water circulates (eg re-used, treated, re-used again, re-treated etc.) in the building system, the less water needs to be drawn from outside; even if this is currently not decisive in countries like Germany due to the large supply of drinking water, it is to be supported from a C2C perspective in order to relieve the external water cycle.

Rainwater: One way to reduce drinking water consumption is to store and use rainwater in accordance with DIN 1989-1; rainwater discharge by the authorities is often limited anyway (and subject to fees), which makes this option more economically viable (ie the tank will have to be built anyway).

Regarding the construction of the corresponding storage tank, care must be taken to ensure that assembly, disassembly and maintenance are as simple as possible. Usually storage tanks are buried or installed in the basement. As a possible alternative, Arup has developed a system that uses a flat roof as the first storage tank (known as a “blue roof”) and then transfers the rainwater to decentralised storage tanks in the immediate vicinity of the toilets, without the need for pumps.³⁵

The necessary treatment of rainwater depends on the intended use. To store the rainwater hygienically, only a filter in the tank inflow and a calmed inflow are required.

³³ Steinbach Ingenieurtechnik, n.d., p. 4

³⁴ University of Southampton, 2015

³⁵ ARUP, 2017

After the storage tank, typically a fine filter is installed; however, this is currently under discussion in the C2C community, as it can cause bacteria to collect on the filter and its installation also leads to algae growth.³⁶ Biocides are used to treat these, but this is not permitted under C2C criteria, because they are not designed for the biosphere. As a result, often no additional fine filter is installed in C2C-inspired environments.

Rainwater is ideal for irrigation of outdoor facilities or facade greening, being even more suitable for the latter than tap water³⁷. This would be the preferred reuse scenario, as hardly any treatment is necessary – it is only necessary to treat the water for hygienic storage and to avoid algae growth in the distribution system.

Rainwater can also be used as process water in the building, both for flushing toilets and for filling the evaporation systems of the ventilation system; however, the systems may require further treatment of the water, so it must be checked for each individual case where such a use makes economic sense.

Where rainwater is used as process water, a further technical treatment (fluidized bed process, rotating body or membrane reactor) is required. Some types of use (eg showers) additionally require UV-hygienisation³⁸ – see explanations in chapter 3.4.2 “Water treatment”.

Separate drinking and process water systems are required for rainwater use, which leads to increased material usage; however, when using C2C-inspired materials, this should be secondary to the use of the system – as much reused water as possible should be used in the building.

A special case is the use of rainwater for washing machines. Due to the lower degree of hardness of the rainwater, less detergent can be used, which leads to fewer chemicals in the water circuit.³⁹ It may therefore make sense to supply a laundry room with rainwater for example.

It would also make sense to use rainwater for cleaning external surfaces of the building; here too, relatively little treatment would be necessary.

Grey water: In principle, for the use of grey water the same notes apply as for the use of rainwater as process water – the required treatment depends on the use and should be checked for each individual case. In addition, a separate wastewater network is required for greywater use; here too, the reuse of water (with the use of C2C-inspired materials) is given higher priority than the saving of material.

When examining the economic efficiency, it should be kept in mind that the use of grey water reduces the amount of waste water and thus also the municipal charges for water supply and disposal. For C2C-inspired buildings, grey water must in any case be treated to the quality level of process water (removal of surfactants, etc.); grey water use in a C2C-inspired building is therefore more economically viable than in other buildings, as the corresponding infrastructure for storage has already been provided.

36 Fachvereinigung Betriebs- und Regenwassernutzung e.V. (fbr), 2017, p. 4

37 Bauer, Mösle, & Schwarz, 2013, p. 63

38 Herbst, 2008, p. 82

39 Benz GmbH, 2016, p. 22

3.4.6 Water production

A reduction in water consumption alone will not achieve a 100% neutral water balance; this would require the production of water of drinking water quality on the site.

This is considered a special case and therefore not considered in detail; for the sake of completeness, however, some considerations on the suitability for compliance with the C2C principles:

Well or spring: A groundwater well is another possible source of water in addition to reservoir water and rainwater. However, the abstraction of groundwater alone is not considered positive in terms of C2C, as the quality of the available water is not increased.

Seawater desalination: For sites located near the sea, seawater desalination is a way of producing drinking water; this is considered a new source of water and is thus included in the balance sheet as a compensation.

However, seawater desalination is very energy-intensive; the most energy-efficient technology possible must be selected, and a supply from renewable sources (wind or solar energy) must be provided. Any potential pollutants used in the process (eg biocides, acids as encrustation inhibitors) must be kept in circulation and are not allowed to enter the biosphere.

Image 5: Industrial scale seawater desalination plant



Where salt can be used as a by-product of seawater desalination as table salt (eg Sylt Sea Salt⁴⁰), this is a sensible re-use as nutrient and to be supported in the sense of C2C; the introduction of the brine into the sea, however, cannot be regarded as a contribution to nutrient positivity.

Water extraction from air: Active water extraction from air (as opposed to condensate being produced as a by-product of de-humidification, which is considered grey water) is a special case of water production in regions with extreme water scarcity and is not covered here; where it is intended to use such a system, it should be evaluated whether the amount of water obtained justifies the use of energy (again depending on the energy source) and material usage.

3.5 System sizing

As soon as the systems are selected, the usual system design specifications and the design criteria defined under “Design criteria and boundary conditions” take effect.

The system should be sized for the minimal amount of tap water consumption; by reducing consumption, the technical feasibility of water positivity is increased and the use of materials is reduced.

At the same time, the systems must be designed in such a way that reused water can circulate within the building as long and as frequently as possible; a separate waste water system (separation of black water; possibly also yellow water) as well as a separate supply system (separation of drinking water) will have to be provided. This has an influence on the space requirement in shafts, facing shells and ceilings.

In general, materials should be used as effectively as possible – only as much of the right material as necessary. The criteria defined in chapter [13 “Material”](#) must be observed.

In all water treatment systems, care must be taken to ensure that no additional harmful substances enter the water cycle.

3.5.1 Rain water usage

The rainwater storage system should be sized according to potential use, not to availability; it makes no sense to store rainwater that will not be used. Depending on the climatic situation and the expected consumption, a reasonable percentage of water consumption to be covered by rainwater use should be evaluated; for green areas and façade greening, as well as for façade cleaning and water connections to the outside facilities, the degree of coverage should be 100% if possible.

Table 7 shows some design examples for greywater and rainwater systems.

Table 7: Examples of buildings with grey or rainwater systems

	Number of users	Cisterns	Roof area	Other data	Comments
Apartment complex Markfeldgasse (Perchtoldsdorf)⁴¹ * Rain Water usage	6 RU (residential units)	12,000 l	500 m ²	Used for irrigation and toilet flushing	October to April complete demand covered by rainwater
Single family house exemplary calculation following König⁴²	5 persons	4,680 l	155 m ²	Used for irrigation, washing machine and toilet flushing	
Horizon house – environment Agency HQ		30,000 l		Non-pressurised system	
Gates foundation HQ Seattle		3,785,000 l		All AHU condensate drainage is routed to the tank (~ 950,000 l in the summer) 61,300 m ² usable area	95% of non-potable water
Office building Regensburg, Germany⁴³	1,150	50,000 l	4,100 m ²	Reduction of drinking water consumption 1,300 m ³ /a	Reduction water costs 2,600 € /a

According to the German Federal Environment Agency, attention must be paid to whether the material of the roof surfaces allows rainwater to be collected: “Soluble and insoluble metal compounds that are harmful to the environment can wash away from roofs made of copper and zinc. Bitumen waterproofing of roofs with tar board can release biocides. The use of rainwater from these areas is not recommended”.⁴⁴

41 Prof. Treberspurg & Reim, 2004

42 Benz GmbH, 2016, p. 45

43 Lagus GmbH, n.d.

44 Umweltbundesamt, 2016

3.5.2 Grey water treatment

The grey water filtration must be sized for treating all grey water in the building; the level of filtration will depend on the intended use.

To be fully C2C-compliant, the filter system would have to be designed in such a way that the water that leaves the building has at least the same quality (= pollutant load) as the rainwater falling on the property area; the results of the water quality testing of the rainwater falling on the site are critical here. This, however, only applies to water leaving the building; the water re-circulating in the building – which will likely require a lower quality – should therefore be maximised.

Table 8 shows examples of capacities of greywater treatment plants.

Manufacturer and product	Application in	User	H x L x W	Water treatment	Price incl. taxes
Iclear 200 indoor L⁴⁵	One family house	2...5	1.7 x 1.5 x 0.7 m	200 l/d	3,850 € €
Energy PLUS Water Recycling Lokus GmbH⁴⁶	Multifamily complex, trade, hotels	20...40	9 m ²	from 1,500 l/d	from 15,000 € €
Aquawell Lagus GmbH⁴⁷	Office Building, Regensburg, Germany	1,150	4 tanks with each 1.7 x 2.1 x 0.8 m	8.000 l/d	60,000 € €

Table 8: Size examples for grey water treatment plants

45 Fachvereinigung Betriebs- und Regenwassernutzung e.V. (fbr), 2017, pp. 84–85

46 Nolde & Partner, n.d., p. 1

47 Lagus GmbH, n.d.

3.5.3 Grey water usage

The grey water network should collate all the grey water produced in the building and should be designed for as many applications of grey water in the building as possible or economically sensible; the distribution network should be optimised according to C2C criteria (material selection) (see chapter 14 “Construction Methods”).

The selected greywater treatment plant must be adapted to local conditions such as space requirements, economy, number and behaviour of users. Table 8 shows exemplary dimensions of plants for greywater treatment.

3.5.4 Black water treatment

The minimum criterion for black water treatment is the use of nutrients. A minimum requirement for the usable quantity cannot be formulated from a C2C perspective – ideally all black water flows will be used, but this will not always be possible due to legal requirements and space problems in urban areas; it also only makes sense to branch off as much nutrients as are usable on the site, so that the design should be project-specific.

Small sewage treatment plants are available in different sizes, for wastewater volumes of 1 to 250 users; they have an average floor area of approx. 4 m² and a height of 1.5 to 3 m and are available from 2,700 € per list price.⁴⁸

Urine separation toilet systems (so-called NoMix toilets) have been used not only in single-family houses but also in larger projects; while this system size has not yet been implemented frequently, the “Saniresch” research project shows that office buildings with 400 users with separation toilets (as vacuum systems) can also be implemented (see 3.5.5 “Use of nutrients” for system sizes). Vacuum toilet systems are also used in large residential building projects (eg Jenfelder Au in Hamburg).

For grease separators, which mostly use the gravity principle, there are no special C2C requirements beyond the legal requirements; the C2C criteria for materiality and design must be observed.

3.5.5 Use of nutrients

The size of composting plants that process the waste material from black water treatment plants into humus should be adapted to the amount of humus or fertiliser usable in the building. An alternative concept can also be to design the system for sale or transfer to neighbouring buildings.

The “Saniresch” project in Eschborn (office building, 400 users) accommodated the entire plant technology for yellow water treatment (MAP precipitation reactor), brown water treatment (model with integrated mechanical pre-cleaning and membrane activation reactor), grey water treatment (model incl. sieve, membrane activation reactor and permeate/process water storage tank) in an operating area of 5.4 m x 4.0 m with a ceiling height of 2.6 m.⁴⁹ A vermicomposter with a footprint of 5 m x 1.6 m was used in the “Komplett” project (office building for 65 people) in Oberhausen (Germany), among other facilities.

Due to the research character of these two projects, no clear statement can be made about the quantities of fertiliser or humus produced.

Table 9 shows size examples for small sewage treatment plants of Mena Water GmbH.⁵⁰

Capacity m ³ /d	Persons (up to)	Area L x W
10	85	8 m x 3 m
25	210	8 m x 3 m
75	625	12 m x 4 m

Table 9: Small sewage plants from Mena-Water GmbH

49 Dr. Winker, 2013, p. 34

50 Mena Water GmbH, n.d.

3.6 Material selection

The choice of materials must prevent water from being contaminated with toxic substances; care must also be taken to use substances suitable for C2C in the manufacturing and processing of materials and equipment.

According to Weißenberger⁵¹, in addition to the surfaces of the building envelope and sealed outdoor facilities (which are not considered here), the individual components with the greatest potential environmental impact (based on a life cycle analysis (LCA) taking into account the ODP, GWP, PE etc.) are (acrylic) bath tubs, ceramics and water pipes (including fittings, without insulation and fixings); systems for greywater or rainwater treatment were not included in this analysis.

Due to a lack of information on the part of the manufacturing companies, there is currently little possibility of insisting on *Cradle to Cradle Certified*TM or similar materials, manufacturing processes or degradability for the materials of the plants; however, it would help the market expansion of the concept to enquire with the manufacturers in each case – maybe this will initiate a rethink.

It would probably also help if MEP designers cooperated with manufacturers to review and pilot (even if only in a part of the installation) C2C-inspired products – this could lead to a rethinking and the development of new products, materials, or construction methods.

3.6.1 Sanitaryware (WCs, urinals)

For toilets (separating toilets and conventional designs) and urinals, there is currently little choice in terms of materiality; ceramics are mostly used, but mineral casting or injection moulding is also used. These are disposed of in the construction waste and not separated - no information was found about recycling applications.

In public buildings such as railway stations, petrol stations, stadiums, etc., toilets and urinals made of stainless steel are often used, as they are vandal-proof; however, they are not always suitable for higher comfort demands. Stainless steel has a high recyclability and is also suitable as a material for C2C use, so that these toilets can be used in C2C-inspired buildings.

At the time of writing, only Gemma Solid Works, which holds a *Cradle to Cradle Certified*TM for urinals and washbasins, is available; the products are made of mineral cast but only have a bronze certification level.

3.6.2 Bathtubs and shower trays

Bathtubs and shower trays are available in either enamelled steel, acrylic or cast mineral.

Since steel already has an existing recycling infrastructure, it could be argued in favour of enamel baths. However, enamel is a coating of several metal oxides, the mixing of which makes single-origin recycling impossible; as a result, enamel also does not comply with the C2C criteria – although a more detailed examination in subsequent work would make sense.

For acrylic and mineral cast tubs, attention must be paid to the C2C-inspired materiality.

Mineral casting is a type of composite material consisting of fillers and binders; it is not intended to separate the substances, which makes it a downcycling product. Until now, mineral castings can only be disposed of as building rubble and are downcycled for road construction.⁵²

Acrylic is a plastic. An evaluation in the context of this work is difficult, since the used acrylic and the used dye particles would have to be examined according to C2C aspects. Until now, acrylic bathtubs have been disposed of in bulky waste; a recycling application is not visible at the time of this work.⁵³

Of the three types, mineral casting seems to be closest to the C2C aims. At the time of writing, only Gemma Solid Works offered *Cradle to Cradle Certified*TM bathtubs and shower trays; its products are made of mineral casting and only have bronze certification.

3.6.3 Washstands and washbasins

Washstands are usually made of stone or cast mineral; washbasins are usually offered in ceramic, cast mineral, stainless steel or enamelled steel.

Information on these materials can be found in subchapter [3.6.2 “Bathtubs and shower trays”](#) and [3.6.1 “Sanitaryware \(WCs, urinals\)”](#); stone is to be considered as ceramic.

⁵² Rampf Holding GmbH, 2018

⁵³ Ökobaudat, 2016a

3.6.4 Sanitary fittings

Image 6: Cradle to Cradle material health certified™ taps by Grohe



At the time of writing, there were no valves with a complete C2C certificate available on the market; at present, only Grohe AG has a *C2C material health certification™* in bronze for the taps of the “Eurostyle” series and platinum for the taps “Eurostyle – Upcycled (Prototype)”.

Most washbasin and urinal fittings are made of brass with chrome alloy. Dismantled valves are already collected and fed into a recycling process.

Chromium alloys are not allowed to be chromium-6 alloys because of C2C suitability. Chrome-6 is on the “banned list” of the C2CPII.

Coloured fittings are not recommended, as the colour pigments employed in the coating process often do not meet the C2C criteria. Mixing the metal and coating materials also reduces the recyclability of the otherwise easily recyclable material.

Copper is highly recyclable and therefore suitable for C2C-inspired buildings; fittings made of copper can be particularly useful in public buildings for hygienic reasons.⁵⁴

3.6.5 Toilet flushing (tank, mechanism)

At the time of writing of this guideline there are no *Cradle to Cradle Certified™* or similar flushing cisterns and flushing mechanisms.

Currently, the most common flushing mechanisms are pressure flushing, tank flushing, or vacuum flushing. The type of flushing is to be selected according to the overall water concept – in general, C2C does not specify any technology. Following the C2C Criteria, a separate discharge of urine and black water would have a higher priority in Germany than pure water saving; however, an efficient mechanism supports compliance with water positivity aims.

Flushing cisterns are usually made of plastic or ceramic; the flushing mechanisms are mainly made of plastic (with individual metal parts). As there is currently no recycling system for ceramics⁵⁵, plastic cisterns are currently preferable, as long as the plastics meet C2C criteria.

The material used for flushing in vacuum toilets depends heavily on the vacuum system used; however, the flushing mechanism requires more material than conventional systems. Whether the additional material consumption cancels the positive effects of the vacuum systems could not be conclusively clarified; this would require more information on the exact material use of the manufacturing companies.

Dry separation toilets are currently only used in small buildings and also have a limited user acceptance, so that they are not covered here.

3.6.6 Waterless urinals

In addition to the basin material (ceramic or injection moulding), the sealing technology must also be designed according to C2C for waterless urinals; at present, either membranes or sealing fluids are used for this purpose.

The company Urimat uses membranes in the urinals as well as a cleaning stone; according to the manufacturer, the stone acts biologically. However, the composition is currently not transparent, and biodegradability is not stated.

According to the German Federal Environment Agency's Environmental Statement of 2012, cleaning stones are classified as hazardous to water;⁵⁶ it could not be determined whether this has changed in the meantime.

The membrane is usually made of silicone rubber. Whether this material meets the C2C criteria still has to be checked in more detail – a request to the manufacturer (Urimat) has not been able to clarify this.

The manufacturer Uridan and other manufacturers also rely on plastic components, but use a liquid for sealing and as odour control system. According to Uridan, the liquid is made of purely plant-based substances and is biodegradable according to Regulation (EC) No. 648/2004⁵⁷. The Wuppertal Institute recommends the systems and states that the sealing liquids are biodegradable.⁵⁸

A more detailed analysis was not possible during the compilation of the guide; a preliminary recommendation is to use liquid as an odour control system.

At the time of writing, there were no *Cradle to Cradle Certified*TM waterless urinals.

3.6.7 Toilet seat & lid

Toilet seats and lids are usually made of plastic; there are alternatives made of wood and composite material.

Plastic: Toilet seats and lids made of plastic can meet C2C criteria if the material is recyclable and optimised according to C2C criteria; this concerns in particular the colour pigments. Seats and lids made of undyed, unmixed plastic should therefore be used.

Wood: Toilet lids made of wood are suitable for C2C in principle, but only if no lacquers are used or only those that are designed for biological circulation (= biodegradable).

At the time of writing there are no *Cradle to Cradle Certified*TM toilet lids.

⁵⁶ Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit, 07.12, p. 48

⁵⁷ Uridan GmbH, 2014

⁵⁸ Wuppertal Institut, 2009

3.6.8 Domestic water pipes

Domestic water pipes are usually designed either as metal (copper, stainless steel), plastic or multi-layer composite material.⁵⁹

The application of C2C criteria does not provide a clear recommendation for a particular material; however, the C2C criteria for material must be observed for all versions. This makes it difficult to use PVC and multi-layer composite pipes (composites are currently extremely difficult to recycle), so this materiality should be avoided as far as possible.

Metal pipes have a long usage phase, which is associated with relatively high initial costs; however, the material retains its value and thus allows the building to be regarded as a material bank when properly installed.

Copper and stainless steel pipes generally have good recyclability according to C2C criteria, as long as the recycling process achieves a high material purity.

Copper pipes are not suitable for water with low pH values⁶⁰; for this purpose, internally tinned copper tubes are also available. Technically it is possible to separate this connection⁶¹; it depends on the recycling service if the tin is collected as a separate material, so confirmation should be sought when the system is to be dismantled.

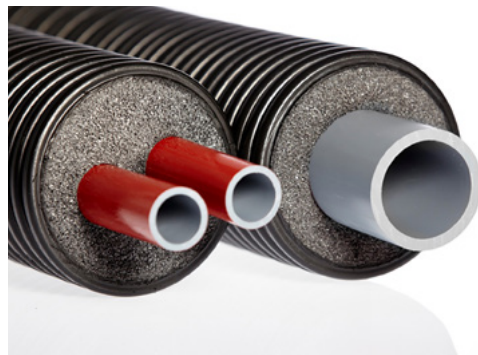
For connecting copper pipes in drinking water installations, according to EN 29454, only soft solders may be used⁶². Currently, soldered connections are not considered a health risk, so that these connections can be used in C2C-inspired buildings.

Stainless steel pipes are very suitable for C2C-inspired buildings as long as connections are pressed and not welded (in which case nickel or chromium could enter the water).⁶³

According to Weißenberger⁶⁴, plastic pipes have the lowest potential ecological impact (according to GWP, ODP etc.), but without taking into account a second or third use cycle of the material. The material must be checked for ingredients – PVC pipes or components are not permitted.

PE pipes can be welded or screwed. Welding takes place without a second material and is therefore not problematic; Screwing can be generally considered C2C compliant.

Image 7: Flexalan 600, Thermaflex



At the time of writing, there is only one *Cradle to Cradle Certified™* water pipe: Thermaflex offers a pre-insulated pipe system (“Flexalan 600”) which is *Cradle to Cradle Certified™* (silver level). It consists of a polybutene pipe with a polyethylene insulation with a HDPE pipe covering. It can be used for heating, cooling and potable water.

59 Umweltbundesamt, 2006
60 Deutsches Kupferinstitut, 2001, p. 3
61 Aurubis AG, 2017
62 Deutsches Kupferinstitut, n.d.
63 Meisinger Ingenieurleistungen, 2018
64 Weißenberger, 2016

3.6.9 Drainage pipes

Drainage pipes are offered as plastic or SML (seamless cast iron) pipes.

The SML pipes are made of cast iron and various lacquers. The pipes can already be made of recycled material⁶⁵, but it is unclear what the lacquers are made of and whether they end up as toxic slag in a recycling process. So far, no sufficient information could be obtained apart from the safety data sheets for the paints; however, some safety risks are already contained in the safety data sheets for the outer lacquer.⁶⁶

SML pipes could be a good C2C solution if manufacturers optimize the used coatings. However, at the time of writing, there are no *Cradle to Cradle Certified*TM SML pipes.

Stainless steel piping is becoming more prominently used for drainage systems (e.g. Blucher). The piping comprises thin-walled stainless steel with push-fit jointing; this would be in principle be considered a C2C-compatible product, as the stainless steel can be recycled.

Drainage pipes can also be manufactured as plastic pipes (mostly polypropylene (PP)). PP as a pure material is easy to recycle and can be produced according to C2C criteria. However, additives (eg color pigments) can be problematic, so generally positive evaluation is not possible; the products would have to be chemically analysed to check whether all ingredients of the PP meet C2C criteria.

Rehau currently offers the only *Cradle to Cradle Certified*TM (Gold level) sewage pipes, made of PP plastic.

3.6.10 Pipe insulation

PE (polyethylene): In principle, PE insulation could meet the C2C criteria, as it is usually a single-variety material. However, the PE insulations available on the market still have to be optimised further in terms of material composition; the material is not allowed to emit toxic exhaust gases in the event of fire, and the use of adhesives for installation and the type of connection (welding) do not meet C2C criteria. The production of PE from renewable raw materials should also be considered.

At the time of writing, only Thermaflex offers *Cradle to Cradle Certified*TM pipe insulations; the “Flexalan 600” pre-insulated pipe system consists of HDPE pipes (one or two in cover pipe), insulation (polyethylene foam) and cover pipe (polybutene material) and reaches the silver level; the Thermaflex “ThermaSmart Pro” insulation (PE) reaches bronze level. Thermaflex also intends to take back old insulation from this system.

Mineral wool (laminated with aluminium): The recycling of stone/mineral wool is theoretically possible⁶⁷, but requires special recycling logistics that are still to be set up. Rockwool takes mineral wool back after the usage phase and makes new mineral wool out of it (“Rock Cycle”); so far, this is limited to material from flat roof products – there is no recycling of this kind for pipe insulation.

⁶⁵ Düker GmbH, 2017, p. 5

⁶⁶ Düker GmbH, 2014

⁶⁷ Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit, 2014

PUR (polyurethane): Pipe insulations made of PUR foam are covered with an outer casing made of PVC. This makes them unsuitable for C2C-inspired buildings, since PVC is on the “C2C-Banned List” of the C2CPII for technical and biological cycle. PUR itself can be based on crude oil or renewable raw materials; according to the German OEKOTEX: 2.4.01, up to now PUR insulation can only be burnt, which may produce toxic gases.

Closed cell foam: There is only one closed cell foam insulation from Thermaflex (“ThermaGo Elast”) with a *Cradle to Cradle Material Health Certified*TM label in bronze. Armaflex develops the “Armaflex ultima” system; it advertises PVC and VOC-free and offers solvent-free adhesives. Whether these products meet the C2C criteria could not be assessed yet and would have to be included in a later revision of the guideline.

Calcium silicate: Evonik offers a calcium silicate insulation with a *Cradle to Cradle Certified*TM label in gold; it does not contain harmful substances and is recyclable according to the manufacturer. Unfortunately, Evonik does not offer it as pipe insulation; however, other manufacturers (eg Johns Manville) do, although without a certification.

Rubber: So far there is no *Cradle to Cradle Certified*TM rubber insulation on the market; however, Armaflex is developing “Armaflex ultra” and advertise that the material is free of PVC and volatile compounds, and offers a solvent-free glue. Whether these products meet the C2C criteria could not be assessed yet and would have to be included in a later revision of the guideline.

Other insulating material: Ecological insulating materials such as tamped hemp can also be considered as an alternative⁶⁸; as long as they are untreated, these natural products can be installed without hesitation in a C2C-inspired building. Depending on the manufacturer, the fire protection class according to DIN EN 13501-1 is specified as B2 or B1.⁶⁹

A possible future alternative could be BioFoam, an aerogel made of a carbohydrate material that is extracted from kelp and red algae and has achieved a “Silver” *C2C Material Health Certificate*TM. It is currently used in food packaging, but the manufacturer (Synbra Technology) is planning to expand into the building industry via its subsidiary IsoBouw.

Adhesive: In addition to the insulating material itself, the frequently used adhesives must be evaluated and selected for use in C2C-inspired buildings; in addition to the materials used in the adhesive, recyclability is reduced by the use of permanent glues, so their use should be avoided.

For PE insulation, there is the option to use a heat plate to melt the insulation pipes together (mainly used for insulation of arches and branches)⁷⁰. This would be the preferred option for C2C-inspired buildings, as it maintains the mono-material quality of the product, which can be recycled better than glued products.

Solvent-free, water-based adhesives are available for pipe insulation (Armaflex SF 990). At the time of writing of this guide, there was no *Cradle to Cradle Certified*TM adhesive available on the market.

68 Hanffaser Uckermark eG, n.d.-b

69 Hanffaser Uckermark eG, n.d.-a

70 Thermaflex International Holding, 2018

3.6.11 Fixings (pipe clamps and mounting elements)

Pipe clamps are usually made of metal; although this is energy-intensive in production, it also generally enables high-quality recycling. Plastic clamps are used between the metal clamps and the to be fastened pipes; these must be optimised according to C2C criteria (eg no use of PVC).

The Adolf Würth GmbH offers a *Cradle to Cradle Certified*TM quick mounting system (Varifix®). According to the manufacturer, little was changed in the conversion to C2C; an alternative to a chromium-6 alloy was found, among other things.⁷¹

The company Mission Rubber Company LLC also offers clamps which is *Cradle to Cradle Certified*TM with silver level; these clamps are especially designed for drainage pipes.

3.6.12 Accessories

Installations such as pumps, mixers, valves, ball valves, flaps, gate valves, ventilation devices and strainers must also be optimised according to C2C criteria. It is not possible to examine all components in detail in this guide; it can only be said that there are no *Cradle to Cradle Certified*TM components at the time of writing.

Valves, ball valves, flaps, gate valves, ventilation devices and strainers mostly consist of messing or red brass (both copper alloys). Both materials are recyclable and mostly already made of recycled material.⁷² There is currently no information available regarding the plastic or electrical parts. At the time writing, there are no *Cradle to Cradle Certified*TM or C2C-inspired installations.

Pumps consist mainly of metal parts and seals; they are generally easy to dismantle, and therefore recyclable. At the time of writing, there are no *Cradle to Cradle Certified*TM or C2C-oriented pumps.

Filter screens of strainers are mostly made of stainless steel and therefore suitable for C2C. The housings are either made of stainless steel or PE and are therefore also potentially suitable for C2C-inspired buildings.

3.6.13 Water treatment plants

There are still no grey or rainwater treatment plants that are *Cradle to Cradle Certified*TM or C2C-inspired and therefore meet the criteria.

Each plant should be checked for its material composition (request information from manufacturers) to store this information in the system passport.

⁷¹ Personal Communication, Matthias Bruhnke Würth GmbH, 26.06.17

⁷² Deutsches Kupferinstitut, 2004, p. 18

3.6.14 Tanks

Rainwater storage tanks are either made of concrete or plastic (according to Fachvereinigung Betriebs- und Regenwassernutzung e.V., mostly PE is used)⁷³. For C2C-inspired buildings, it is not recommended to use concrete storage tanks, as concrete can only be reused by downcycling; plastic storage tanks may be suitable, but care must be taken that the material is optimised for C2C recycling.

3.6.15 Rainwater filter

Most filters are made of stainless steel or plastic, typically with a PE housing; however, there are also filter systems that have a stainless steel housing.⁷⁴

Although according to C2C criteria stainless steel is not generally to be preferred over plastics, due to the lack of information available from the manufacturers, this would currently be considered the most appropriate approach for C2C-inspired buildings – the composition of the plastics is not defined and therefore does not guarantee high-quality recycling and material health according to C2C criteria.

Membrane filters are often used in the case of heavy soiling from the drained surfaces or for treatment to drinking water quality. Information on the exact material composition of the membranes for water purification to drinking water level is not publicly available. However, typically hollow fibres (pore size approx. 15 nanometres) made of plastic are used in these filters; these can be cleaned mechanically or chemically. Whether these hollow fibre membranes are suitable according to C2C criteria depends on the choice of plastic and the recycling concept. At the time of writing, there is no information on closed recycling concepts available from the manufacturing companies.

There are also activated carbon filter systems, which are only used for smaller amounts of water as canisters (Lifesaver Jerrycan) and therefore are not considered here.

3.7 Construction methods

For water and sewage systems, as for all systems, good accessibility and dismantlability should be ensured (see chapter 14 “Construction Methods”).

To facilitate disassembly, sanitaryware should not be glued with silicone or similar.

For connecting copper pipes in drinking water installations, only soft solders in accordance with DVGW Code of Practice GW 2 and EN 29454 should be used.⁷⁵ According to the current state of knowledge, soldering does not pose a health risk, so that these connections can be used in C2C-inspired buildings.

PE pipes can be welded or screwed. Welding takes place without a second material and is therefore acceptable; screwing is in principle C2C-compliant as well.

Flush-mounting and casting-in is to be avoided as far as possible; in toilet / wet areas, accessibility can also be achieved with suitable pre-wall installations (as long as the pre-wall construction is built from C2C-inspired materials).

Pipe openings through walls are to be designed in such a way that disassembly into individual material varieties is possible. If possible, fixings should not be welded on; screw or clamp connections are to be preferred.

The distribution routes should be as short as possible.

A modular design of plants and installations should be preferred where possible, as this enables the simple dismantling of entire components and their reuse.

From a C2C point of view, tanks should be provided as separate components and not as an integrated part of the building (eg watertight walls).

4. Gases and fuels

4.1 Aims and evaluation criteria

4.1.1 Overview

C2C aim	No hot combustion Using only fuels produced on site
C2C minimum criteria	Exhaust gas filtration / no air pollution
C2C no-go criteria	Usage of fossil fuels or fuel from energy plants
C2C material criteria	See chapter 13
C2C construction methods	See chapter 14

4.1.2 Explanation

This chapter covers all fuel types, even if they may fall into different cost groups (eg gases, liquid and solid fuels to heat generation or emergency power supply). The following fuel types were considered:

- Gases for combustion (natural gas, hydrogen)
- Liquid fuels (diesel, ethanol)
- Solid fuels (wood, coal)

Technical gases are considered a special case and are not assessed in this document.

For the evaluation it is to be considered that gas installations include the entire gas pipe network, the gas supply, and the combustion of gas for heat and electricity generation and cooking. The same applies to fuel supply.

As a C2C vision for fuels, the C2C principle of the “use of renewable energy” can be applied. Fuels from fossil fuels are categorically excluded; the use of natural gas, crude oil or products derived from it, lignite or hard coal is therefore not permitted in a C2C-inspired building.

Even the use of biogas and biodiesel is controversial within the C2C community; in this guide the position is taken that the use of energy from direct solar radiation is preferable and that energy crops do not comply with the C2C concept. Fuel obtained by fermentation from biological material that can no longer be used for anything else than composting can be used in a C2C-inspired building – provided the C2C criteria are met during extraction.

The burning of wood – even without its previous cascade usage, eg as a building material – is declared climate-neutral in the literature. However, this can only be seen as an intermediate step and not as a goal – wood is too valuable to be burnt directly as a single use material.

So-called wind gas is accepted for C2C use if it is produced 100% from renewable sources (solar energy or tidal energy can also be used instead of wind energy).

Hydrogen can also be used in combination with a fuel cell (cold combustion) if it is obtained from renewable sources and raw materials (ie from water and not from natural gas).

The use of fuels in the systems of a C2C-inspired building must not affect the aims of clean outside air and indoor air quality; pollutants must therefore be filtered out of the exhaust gas, and leakage of potentially harmful fuels must be detected.

For a carbon-positive cycle, the gases and fuels may only be used if the resulting exhaust gas is used as a nutrient for plants in the building (which in turn increase air quality). This actually excludes hot combustion, as the pollutants and dusts produced are currently filtered, but the resulting residues cannot be fully reused. Whether the pollutants can be used elsewhere in the techno- or biosphere according to C2C criteria would have to be considered in further research.

All components of the gas/fuel systems are to be built with C2C-inspired materials suitable for the defined use scenario and installed according to the C2C criteria for construction. In addition, the information on the used material and the installation type must be documented in material passports.

Figure 5 shows an overview of the components of a gas / fuel system in a C2C-inspired building.

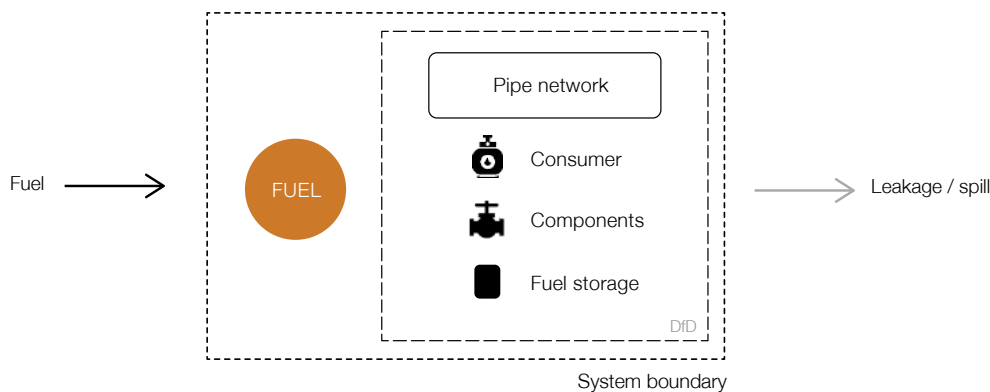


Figure 5: Overview gas system in a C2C-inspired building

4.2 Means of implementation

Avoiding hot combustion will depend on the “System selection” for heating systems – see corresponding chapter.

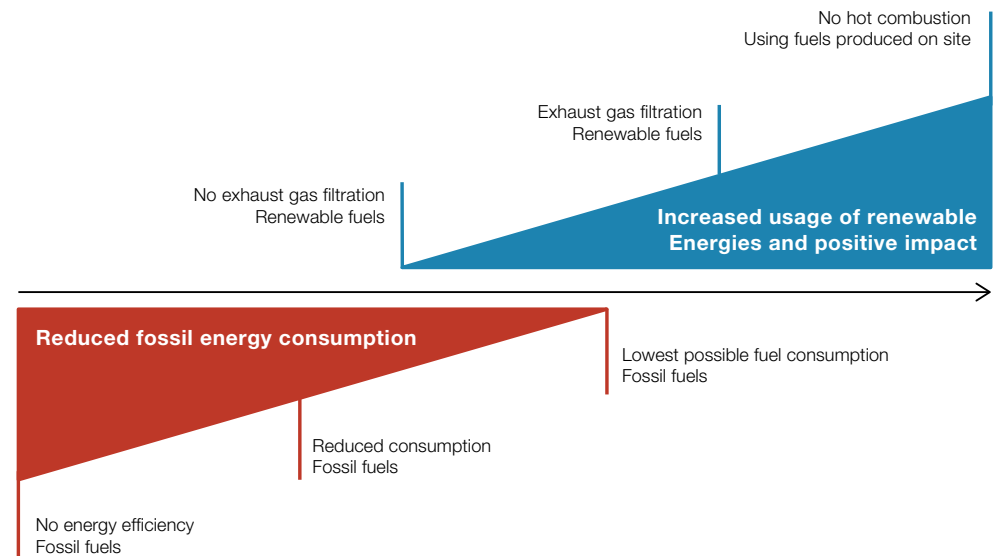
Where hot combustion is employed, exhaust gas filtration should be considered; technologies are available, but usually not economic at commercial building scale – the uptake will likely depend on the local legislation.

A major point in gases and fuels is to avoid using fossil fuels or fuel from energy crops; while some of it will depend on the system choice for the heating systems, the selection of a suitable fuel will play an important part; currently so-called “wind gas” is the preferred choice, or the production of non-fossil fuels on site.

Where fossil fuels cannot be avoided, their consumption should be reduced; this is again covered in the chapter on “Heating systems”.

Figure 6 shows a classification of the various possible steps in the field of gases and fuels.

Figure 6: Roadmap for gases and fuels in C2C-inspired buildings



4.3 Design criteria & boundary conditions

During the establishment of the brief, it must be identified whether gases or fuels are to be used in the building systems and if so, how the exhaust gases can be cleaned or used as a nutrient for the biosphere of the building; conflicts with other C2C aims (eg air quality, but also economic efficiency) will also have to be taken into account.

In principle, the combustion of gases or fuels (even those regeneratively produced) in the building should be kept as to a minimum or ideally avoided completely; this may result in additional design criteria for other systems, eg for heat generation or kitchen design. **Figure 5** shows a classification of the various measures and steps in the field of gas and fuels.

If a use of gases and fuels is planned, it must be established where the gases or fuels comes from and how it is ensured that they meet the minimum C2C criteria (no fossil fuels, no fuels from the cultivation of so-called energy crops).

The availability and type of delivery of the gas or fuel (from a gas distribution network, tank trucks) must also be clarified; the resulting boundary conditions (network or filling connection, connection conditions; storage) must be established.

If required, it should be defined whether and how much gas or fuel is produced in the building itself, eg by gasification or fermentation plants.

The level at which the exhaust gases are to be cleaned of pollutants, as well as the degree to which the nutrients in the exhaust gas are to be used, must also be defined.

A treatment of the exhaust gas to an ODA 1 value (according to EN 13779) would be possible an aim. It should be considered that DIN 13779 still refers to WHO guidelines from the year 1999; for C2C-inspired buildings, the new WHO guidelines from the year 2005 are to be aimed at. Table 10 shows the relevant pollutants according to WHO, as well as the corresponding maximum values from 1999 and the improved values from the “WHO Air quality guidelines for particulate matter, ozone, nitrogen dioxide and sulphur dioxide” 2005.

Table 10: WHO guide values for relevant air pollutants

Harmful substance	Averaging period	Reference value [$\mu\text{m}/\text{m}^3$]	
		DIN 13779 (WHO 1999)	WHO 2005 guideline ⁷⁶
Sulphur dioxide SO ₂	10 minutes	-	500
	24 h	125	20
	1 year	50	-
Ozone	8 h	120	100
Nitrogen dioxide NO ₂	1 year	40	40
	1	200	200
PM10 suspended solids	24 h	50	50
	1 year	40	20

To define the level of exhaust gas cleaning, the average wind speed is to be determined during the establishment of the brief, which together with the cross-section of the building in the main wind direction is used as a reference value for the calculation of the permissible exhaust gas values.

To be able to use exhaust gases as nutrients, their composition must be established, and the nutrients must be supplied either to the techno- or biosphere.

A boundary condition is the necessary safety precaution for the use of fuels in buildings (fire or explosion protection); the relevant regulations must be identified, and their requirements listed. There are established regulations for diesel and natural gas; regulations for the storage and distribution of hydrogen may be less established and more difficult to meet.

The economic aims for the implementation of the C2C aim may result in further design values, eg optimisation of the space consumption of storage facilities, etc.

4.4 System selection

When selecting the system, it is important to consider how the C2C-criteria can be met; this concerns

- Sources of gases / fuels
- Storage of gases / fuels
- Usage of gases / fuels
- Treatment of exhaust gas
- Use of nutrients in exhaust gas

The system selection for heat generation and electrical installations may also play a role here – see corresponding chapters.

4.4.1 Sources of gases / fuels

Due to the great debate about the sustainability of certain fuels, the following section describes how various fuel types comply with C2C criteria. In each case, the origin of the gas / fuel will be important; the use of fossil fuels in C2C-inspired buildings is not acceptable.

Biogas: The sole purchase of biogas is not yet a C2C-compatible solution; in addition to the origin, it is also important to pay attention to the use of the resulting waste gases or nutrients (see explanation in chapter [4.1.2 “Explanation”](#)).

When purchasing biogas, it should also be confirmed that it is not entirely from landfill gas or contains gas from cultivated energy crops.

Landfill gas is derived from the degradation processes in waste landfills; from C2C point of view, it is not a gas from regenerative sources, as there should be no more landfills, since no more garbage will be produced, and hence no more gas will be available. Nevertheless, it makes sense to use the gas, which is produced anyway, as an energy source; however, it is considered an intermediate step and not the ultimate solution, and landfill gas should not be the sole gas source for a C2C-inspired building.

From a C2C point of view, the use of energy crops in their production speaks against the purchase and use of biogas – according to the C2C concept, it does not make sense to use the soil for the cultivation of energy crops if food could grow on the same soil.

Most biogases currently available on the market contain proportions of gas obtained from energy crops; even the “Green Gas” seal also permits gas from energy crops (even if care is taken to ensure that cultivation is as ecological as possible). As an alternative, the biogas of “EWS-Schönau” can be mentioned, which extracts gas purely from residual materials.

Image 8: Production site for windgas



Another interesting approach is the purchase of so-called windgas (power-to-gas) supplied by Greenpeace Energy eG. When this gas is generated, excess electricity from renewable sources is used to drive an electrolyser to separate water into hydrogen and oxygen. The hydrogen is either directly fed into the natural gas grid or after conversion to methane (binding CO₂ in the process) and the oxygen is released into the environment; the windgas can then be used like natural gas. Windgas is CO₂-neutral because either it does not produce CO₂ during its combustion, or CO₂ is bound during the production of the methane.⁷⁷

Where the supplier feeds into the public grid, it is not necessary to bring the gas directly from such producers to the building; just as with green electricity, buying the gas from the supplier is sufficient. Where this is not an option, storage may be required when purchasing biogas; see chapter 4.4.2 “Storage of gases / fuels”.

Biodiesel: The same requirements as for biogas apply to biodiesel – fossil diesel is excluded, and a possible content of diesel from energy crops must be avoided. As an alternative, biodiesel can for example be produced from refined used cooking oil.

When biodiesel is purchased, storage must be provided; see also chapter 4.4.2 “Storage of gases / fuels”.

Own production: There are possibilities to produce biogas by a biogas plant integrated in the building, or hydrogen by an electrolyser. No information was found on the decentralised production of biodiesel or ethanol, although this would be technically possible in principle.

A special case is the use of old cooking oil from canteen kitchens to drive emergency power generators; even if combustion processes are generally to be rated as difficult according to C2C criteria, these can be rated less badly such re-used fuels.

The biomass produced in the building (food leftovers, etc.) could be collected in a micro-biogas plant; this could close local cycles. In warmer climate zones, there are already companies that offer such micro plants (eg HomeBiogas); these plants are currently not yet economically viable in Germany.

Using an electrolyser, it is possible to convert the excess electricity from a PV or wind power plant into hydrogen; this principle can be a good solution for a building in combination with a hydrogen storage tank and a fuel cell heating system and is used, for example, in an energy self-sufficient apartment building in Switzerland.⁷⁸

The gas production equipment has to be optimised according to C2C-inspired materials and corresponding construction methods. At the time of writing the guidelines, there was no plant with *Cradle to Cradle Certified*TM gas production equipment or systems with equivalent materials or C2C compliant construction and documentation.

Pellets: Where wood is used as fuel, the fuel should only be produced from wood waste (eg sawdust; also: olive pits). With wood as a heat source, at best climate neutrality can be achieved, since exhaust gases are produced during combustion; burning wood is thus only an interim solution.

4.4.2 Storage of gases / fuels

In many cases, regenerative gas or fuel will not be available directly from the grid; there will also be cases where there is no grid connection. In these cases, storage needs to be provided.

The storage of gas or hydrogen can also be a good way of compensating for weather-related fluctuations in solar electricity or heat production. Whether a storage facility can be built at all depends on the available space and – especially in the case of hydrogen – on the corresponding codes and regulations; this would have to be clarified at an early stage as this would restrict the choice of systems.

In the case of gas storage, from a C2C point of view it makes no difference if gas is stored as a liquid pressurised. Liquid gas can be used for all applications, also in conjunction with a fuel cell; for other technologies, the disadvantages of the system options described in the chapter 5.4.2 “Heat generation” for condensing boiler technology have to be considered.

Notwithstanding the above, the increased energy consumption for the production of liquefied gas is a disadvantage; gas produced by a biogas plant can be stored more easily in a pressurised tank. The more complex structure of liquid gas tanks is another aspect which, according to C2C criteria, would be a negative aspect of this technology.

LNG (liquified natural gas) tanks can also be rented;⁷⁹ an advantage of renting is that the tank owner is responsible for the liquefied gas tank and will be required to use permanent quality.

Materiality requirements apply to the storage tanks, which are discussed in more detail in the chapter 4.6 “Material selection”; this could influence the system selection.

78 Umwelt Arena AG, 2016

79 Knauber Gas GmbH & Co. KG, 2017

4.4.3 Uses of gases / fuels

For heating: Mere combustion of fuels for heat generation is not in the spirit of C2C; even combined heat and power generation (CHP) would only be classified as ‘less bad’. The ratio of heat and electrical consumption, as well as heat demand in summer by the different functions of the building will play a role in this evaluation.

From a C2C point of view, the CHP systems do in principle not differ from conventional systems (emergency generator, heat exchanger); however, it has to be examined whether the systems are suitable for the use of sustainably produced fuels. In addition, a review of the exhaust gas quality and a concept for exhaust gas utilisation must be provided (see chapter 4.4.5 “Use of nutrients in exhaust gases”).

In a fuel cell, gas is used in a ‘cold combustion’ in which neither carbon monoxide nor fine dust is produced.⁸⁰ This also allows better use of the exhaust gas as a nutrient source for plant systems in buildings. For this reason, the use of fuel cell technology would be preferable from a C2C point of view.

For further explanations and evaluations of fuel cells see chapter 8.4.1 “Electricity generation”.

For electricity generation: The generation of electricity from fuels in buildings is rather a special case, as this is only economical in the case of very high outputs or a lack of a public electrical grid. This case is not dealt with in this guideline, but similar requirements apply as for heating. Information on power generation can be found in the chapter 8 “Electrical installations”.

A more frequent case is the operation of emergency power generators; these usually consist of diesel-powered combustion engines with an AC generator. The minimum solution here would be to ensure the use of regeneratively produced diesel or ethanol; this may influence the choice or design of the equipment.

Whether battery systems or emergency power generators are to be used to generate emergency power is dictated – as with other safety-relevant systems – by the codes and regulations for the selection of the emergency power supply; the safety of users and the environment is central and is not to be undermined by C2C criteria.

None of the technologies available for emergency power generation currently fully meet the criteria of the C2C concept; neither battery systems, fuel cells nor emergency power generators fulfil C2C material criteria or are completely designed for the bio- or technosphere.

Diesel or gas emergency power generators produce harmful exhaust gases despite the use of biofuels; for this reason, battery systems or systems with fuel cells would be preferable to combustion systems in C2C-inspired buildings.

When considering the use of materials, it is currently difficult to estimate which technology is less harmful. The company Aquion Energy, which manufactures *Cradle to Cradle Certified*TM batteries (as of September 2018) is in the process of resuming production after a temporary insolvency; if these batteries can be used for emergency power generation, this technology is preferable.

Uninterruptible power supply (UPS) systems can also be equipped with fuel cells;⁸¹ this is to be preferred to a conventional battery system (for information on fuel cells, see chapter 8.4.1 “Electricity generation”). The advantage of this option lies in the possibility of cold combustion of renewable energy sources. Whether a UPS with fuel cell can also replace the emergency power generator would have to be evaluated on a case-by-case basis.

It should be noted that this is only a preliminary assessment, and the use of materials and a lifecycle cost of battery and emergency power generators should be checked in a project-specific analysis.

For cooking: The C2C criteria must also be observed when using fuels for cooking. This applies both to the choice of fuel and to the cleaning of exhaust gases.

Due to the small quantities involved and the associated safety issues, it must be clarified in each case whether combustion with gas for cooking makes sense. Nowadays, modern kitchens are operating with induction technology; building owners also shy away from using gas because of the increased safety requirements for storage and distribution. However, C2C does not rule out the use of gas as such, as long as the C2C criteria are met.

4.4.4 Treatment of exhaust gases

Where combustion is used, a system for exhaust gas cleaning and for the use of the nutrients in the exhaust gas has to be provided in C2C-inspired buildings; this also applies to emergency power supplies.

Up to now, codes and regulations do not require additional exhaust gas treatment (beyond the gas condensation this technology already provides) for condensing boilers in buildings, and manufacturers do not tend to offer such technologies. For pellet heating, in some cases electrostatic fine dust filters are being used.

As additional exhaust gas treatments, exhaust gas scrubbers (absorbers) or adsorbers are conceivable; these are technologies that are currently only used in large-scale plants, but are also available in small sizes.⁸²

Crucial for the selection of the system according to C2C criteria is not only the selection of the sorbent (water in the case of flue gas scrubbers, activated carbon in the case of adsorbers, plastics or other) but also a clarification of what happens to the filtered substances; currently, they cannot be recycled according to C2C criteria.

At the time of writing, there is no *Cradle to Cradle Certified*TM exhaust gas treatment system available on the market. A clear statement as to which technologies are better suited is currently not possible due to the lack of material information (sorbents etc.). The best solution has to be found for the respective project; as a target for C2C-inspired buildings, the use of technology that generates exhaust gas should be replaced by clean technologies.

81 Krimmling, Deutschmann, Preuß, & Renner, 2014, p. 322

82 Infiltec GmbH, 2004

4.4.5 Use of nutrients in exhaust gases

The only nutrient that can be used in ‘normal’ buildings up to now is CO₂. To facilitate its use, combustion should ideally be carried out in such a way that no other substances get into the exhaust gas, which is the case, for example, with the cold combustion of a fuel cell.

This ‘clean’ CO₂ can be utilised if biological filters (ie plants) are used; the exhaust gas could be passed (together with the exhaust air of the ventilation system) into greenhouses, over green facades or green roofs, and thus serve the plants as a nutrient.

In this sense, an integration of indoor vegetable gardens in the building would be a good solution for exhaust gas utilization or CO₂ utilization (carbon dioxide fertilizer).

Another special solution is an algae façade, in which algae store solar energy in a nutrient solution (Arup, SolarLeaf); CO₂ is required for the photosynthesis process of the algae, which would also be a suitable use under C2C aspects.

In greenhouses, the exhaust gas from heat or electricity generation processes can be used as a nutrient after it has been pre-treated with SCR (Selective Catalytic Reduction) and oxidation catalysts;^{83,84} a use in a building-integrated greenhouse is therefore conceivable. Whether the filtered residues can be used in accordance with C2C criteria could not be finally clarified during the preparation of the guideline.

In the Venlo city hall, for example, the SO₂ and NO_x content of the filtered outside air, including car exhaust fumes, is each reduced by 30% through the green façade.⁸⁵

83 GE Power & Water, 2014

84 H+H Engineering & Service GmbH, 2018

85 Van Loon, 2016

4.5 System sizing

As soon as the systems have been selected, the usual specifications of the system design as well as the design criteria defined under “Design criteria and boundary conditions” apply. In addition, the suitability of the selected plant for the use of regeneratively generated fuels must be confirmed, and the impact of the exhaust gas cleaning system must be taken into account.

During the system design, the annual exhaust emissions of the systems have to be determined, to establish the necessary level of exhaust gas cleaning and to check compliance with the C2C brief.

Since the systems may conflict with other C2C criteria (eg economy; fresh air cleaning), priority should be given to reducing consumption; only a supply for minimised consumption should be aimed for.

Under certain circumstances, a C2C gas system requires more space due to the necessary storage of the gas (instead of a network connection). The exhaust gas cleaning system – which is also required for liquid or solid fuels – will also take up additional space.

Table 11 gives an overview of some micro biogas plants that can be operated in warmer climates without significant technical effort; however, they are not yet automated in any way. In Germany, the operation of such plants is difficult because of the temperatures needed (warm).

Technology	Plant size	Costs	Biogas production	Other
HomeBiogas 2.0	2.1 m ³	approx. 400 €	700 l/d 4.4 kWh	Fertilizer production 12 l/d
Puxin PX-ABS-3.4M3	3 m ³	210 €	1,000 l/d	
PuxinPX-ABS-15M3	15 m ³	850 €	8...10 m ³ /d	

Table 11: Examples of miniature biogas plants for use in warmer climates

Table 12 shows a brief overview of the hydrogen technology used in an energy self-sufficient apartment building in Switzerland.⁸⁶

Table 12: Hydrogen technology energy self-sufficient apartment building in Brütten (Switzerland)

Technology	Producer	Type description	Dimensions W x D x H	Technical information
Electrolyser	Proton OnSite (USA)	Hogen H2/PEM	180 x 81 x 191 cm	Electrical output 14.5 kW Yield: 2 m ³ /h hydrogen (30 bar) Thermal output 8 kW / 35°C
Tank system and piping	Elkuch AG	Special hydrogen tank	Tank 1: length 9.2 m diameter 2.7 m Tank 2: length 13.5 m diameter 2.7 m	2 tanks Total capacity 120 m ³ (max. 30 bar)
Fuel cell	Proton Motor Fuel Cell GmbH	PM Cube S 5	80 x 46.5 x 30.8 cm	Electrical output: 6.2 kW / 5.6 kW (continuous output) Thermal output: 5.5 kW (continuous output) 60°C

Apart from the obligatory material and construction criteria, C2C does not require any further considerations for the design of the storage systems – the conventional design and safety criteria must be observed.

To reduce consumption, passive (eg thermal insulation) or regenerative measures (eg solar heat utilisation) should be prioritised; this is to be considered in the design of the corresponding systems, and the respective designers must be involved in the process.

For optimum material usage, the pipe runs should be kept to a minimum; tanks should be positioned as close as possible to filling stations and / or consumers.

4.6 Material selection

As far as materials of the equipment in gas and fuel systems are concerned, there is currently little possibility of insisting on *Cradle to Cradle Certified*TM or C2C-inspired materials, manufacturing processes or dismantlability due to a lack of information on the part of the manufacturing companies; however, it would help the market spread of the C2C concept to inquire with the manufacturers in each case – this could possibly initiating a rethink in the industry.

It would probably also help if MEP designers cooperated with manufacturers to review and pilot (even if only in a part of the installation) C2C-inspired products – this could lead to a rethinking and the development of new products, materials, or construction methods.

4.6.1 Gas pipes

Gas pipes are currently mostly made of metal (steel, copper); this means good recyclability (but very energy-intensive). Utility providers commonly use medium density polyethylene (MDPE) for their distribution; however, this material is not used in buildings.

In the case of metal pipes, particular attention must be paid to efficient installation and the type of connections. Flanges are typically used for the latter; here, attention must be paid to the type of gasket – it should be meeting the C2C criteria for materiality. Up to now, the seals are largely made of nitrile-butadine rubber (NBR), graphite material, or fibrous material.⁸⁷

To determine which of these materials is more suitable according to C2C criteria, a chemical analysis would have to be carried out; this was not feasible within the scope of the creation of this guideline. However, there are currently no *Cradle to Cradle Certified*TM seals for pipes.

Metal pipes also usually require a corrosion protection; the requirement for such a protection depends on environment (internal or external) as well as on the type of installation (surface or flush mounting).

For indoor installations, copper pipes can be installed without additional corrosion protection unless they are cast or plastered in.⁸⁸ For flush-mounted installation, a plastic coating (usually made of PE) in accordance with DIN 30672 is required. This would have to be optimised in accordance with the C2C criteria, which is not yet the case, so this type of construction should be avoided; see also the notes under [“4.7 Construction methods”](#).

In the case of steel pipes, most surface-mounted installations can be covered by galvanizing (EN 10240). A galvanisation allows recycling according to C2C criteria if the zinc has a high and tested quality / purity. ZINQ is the first manufacturing company whose zinc and process is *Cradle to Cradle Certified*TM. For this reason, galvanising is preferable to other corrosion protection materials, as far as safety regulations allow.

⁸⁷ Steinbach, 2015

⁸⁸ Deutsches Kupferinstitut, 2010, p. 24

Flush-mounting should also be avoided as far as possible in this case, to facilitate dismantling and recycling of the pipes. In a way this is favoured by local or national regulations, which typically require gas pipes to be installed in a ventilated enclosure.

Where a yellow coating or painting of the gas pipes is required, this would also have to be optimised according to C2C criteria. An assessment as to which type of paint is to be preferred according to C2C could not be made within the scope of the guideline, as a chemical analysis would have to be carried out. As a rule of thumb, acrylic lacquers are preferable to synthetic resin lacquers – but acrylic lacquers also contain organic solvents and should therefore be used as little as possible.

In addition to metal pipes, plastic composite gas pipes are also used. These are usually made of cross-linked PE (PE-X); this material cannot yet be recycled to an equivalent quality, so, its use is not to be recommended in a C2C-inspired building.⁸⁹

According to DIN 30690-1, gaskets must be provided with the minimum data (manufacturer, type, material, nominal pressure, nominal size); this is already the beginning of a material tagging⁹⁰ according to the C2C criteria (“material passport”).

Threaded pipes should be preferred if the relevant codes and regulations allow it and these pipes allow reuse of the connection technology. At the time of writing, there were no *Cradle to Cradle Certified*TM gas pipes.

4.6.2 Fuel pipes

If an emergency power supply with combustion engine is planned in a building or industrial plant, fuel lines are required. Due to the hazardous nature of the fuels, all safety aspects must be observed for these lines – they are to be given priority over C2C considerations.

Stainless steel (single or double-walled) with a plastic coating (PE or similar) is often used for fuel pipes.⁹¹ The plastic coating makes it difficult to recycle the fuel pipe. Stainless steel is easy to recycle but requires a lot of fossil energy. It is technically possible to separate the plastic from the stainless steel, but it is not possible to clarify within the scope of this work whether the plastic can then be fed into a pure and high-quality recycling cycle. In principle, therefore, the aim should be to keep the pipe runs as short as possible.

At the time of writing, there are no *Cradle to Cradle Certified*TM fuel lines.

⁸⁹ Avraam & Keyuan, 2014

⁹⁰ Steinbach, 2015

⁹¹ Rex Industrie Produkte, n.d.

4.6.3 Accessories

Accessories such as valves, regulators, pressure gauges or strainers must also be optimized according to C2C criteria.

The materials of valves, regulators and strainer are similar to those of water supply systems. See the specifications in the corresponding section 3.6.11 “Fixings (pipe clamps and mounting elements)”.

At the time of writing, there are no *Cradle to Cradle Certified*TM internals.

4.6.4 Fastening systems

The material of the fastening systems is similar to that of water pipe fastenings. See the specifications in the corresponding chapter 3.6.11 “Fixings (pipe clamps and mounting elements)”.

4.6.5 Heat- and electricity production

The chapter 5 “Heating systems” addresses boilers, while the chapter 8 “Electrical installations” deals with fuel cell technology and emergency power generators – see the explanations there on material selection.

At the time of writing, there is no heat or power generation system made of *Cradle to Cradle Certified*TM or equivalent materials respectively C2C-compliant construction and documentation.

4.6.6 Storage

Gas or liquid fuel storage tanks are usually made of metal and are therefore generally easy to recycle. The alloys or paints used must be optimised according to C2C criteria.

At the time of writing, there are no gas storage facilities made of *Cradle to Cradle Certified*TM or equivalent materials or C2C-compliant design and documentation.

4.7 Construction methods

When designing gas and fuel systems, all regulatory safety measures must be observed. Due to the increased safety requirements for pipelines with flush-mounted installation, and also to meeting the dismantlability requirements of the C2C concept, surface-mounted should be favoured wherever possible.

4.7.1 Press-fit connections

Press-fit connections such as those made by Victaulic have some advantages such as quick installation. A major advantage of this connection technology is that the pipe system – in contrast to welding – can still be dismantled and thus complies with the C2C criteria for construction.

However, for the connections, various plastics (EPDM, Nitrile, HNBR) are used as sealing material; in addition, a lubricant must be applied to the plastic. The manufacturer (Victaulic) states on its homepage that the type of connection causes plastics to have a longer life expectancy than flange connections.

To date, none of these gaskets has been optimised according to C2C criteria. A statement as to which plastic is recommended cannot be made without chemical analysis. The composition of the gaskets is also not transparent; as a result, no clear statement can be made here about the C2C-suitability of press-fit connections.

4.7.2 Brazing of copper pipes

Brazing results in a strong joint that reduces the reusability of the tubes. However, safety factors are decisive for gas pipelines, so there is no alternative here.

Whether C2C criteria are met by brazing depends not only on the type of joint but also on the brazing material selected; the use of solder leads to a reduction in the quality of the material. According to EN ISO 17672, either copper-phosphorus mixtures or silver-containing brazing alloys are used; which solder has a higher influence on the material quality could not be finally clarified during the preparation of the guideline.

4.7.3 Clamp connections

Compression fittings are allowed for natural gas pipelines up to and including a diameter of 28 mm.⁹² Clamp connections can be dismantled and thus meet the C2C criteria for construction methods. The materiality is still to be clarified, but apart from a small sealing ring, the screw connections are completely made of metal.

The clamping connections do not reduce the material quality of the pipes. Therefore this connection technique is recommended, also due to the lacking information on the materials of the other connection types.

5. Heating systems

5.1 Aims and evaluation criteria

5.1.1 Overview

C2C aim	100% renewable heat coverage
C2C minimum criteria	Own renewable heat generation
C2C no-go criteria	Heat from fossil sources
C2C material criteria	See chapter 13
C2C construction methods	See chapter 14

5.1.2 Explanation

The aim of C2C-inspired heating systems is to cover 100% of the building's heating demand from renewable sources, preferably produced on site, and implementing passive measures. Any possible surplus should be used (eg for a district or local heating network, algae cultivation, vertical farming, etc.).

Chapter 4 "Gases and fuels" explains the handling of fossil and regenerative fuels according to the C2C concept; the specifications listed there also apply here.

On-site renewable heat production refers to heat generated from renewable sources and on site; it can be passive and active.

Passive measures for heat production (eg glazing portions of the façade, shape or orientation of the building) do not use external energy to generate heat during operation; active regenerative heat production exclusively uses solar energy, geothermal energy or regeneratively generated energy sources (see chapter 4 "[Gases and fuels](#)").

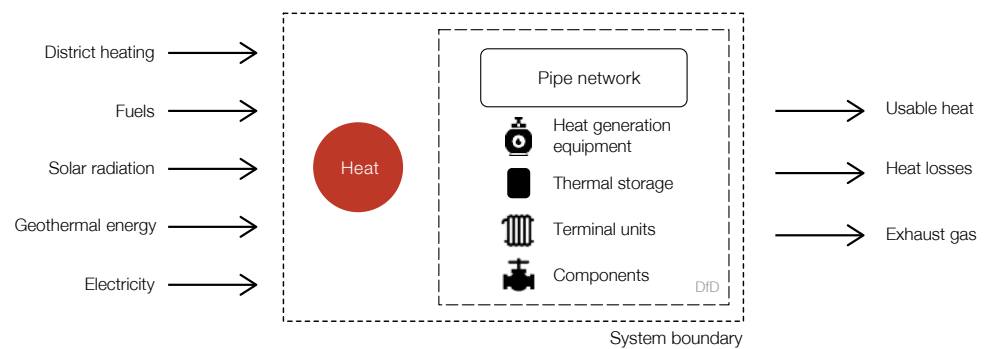
As a minimum criterion, the use of renewable heat generated on-site is required. A minimum percentage requirement for the degree of coverage is initially considered to be unnecessary (as soon as a regenerative system has been introduced, maximum use is usually a matter of self-interest) – in every project, the aim should be to achieve the greatest possible degree of coverage of self-generated regenerative energy.

In C2C-inspired buildings, a further focus is on a healthy environment for its users. To support this aim, the heating systems and their controls must be designed for high comfort (including psychosomatic effects) and a high degree of user control.

In the guideline, all disciplines are considered individually and individual aims are formulated. However, the electrical installations, heating installations and cooling installations can pursue the aim of positive energy self-sufficiency as an integrated, overall system. The boundary for the energy balance should be set over the entire MEP installation and an overall energy concept should be drawn up, which does not only consider individual disciplines; for example, the use of electricity for heating would be acceptable in the case of regenerative power generation, or the waste heat generated in the generation of electricity could be used for heat supply.

Figure 7 shows an overview of the corresponding energy flows and systems to be considered for a heating system.

Figure 7: Overview of a heating system



5.2 Means of implementation

Achieving a 100% renewable heat coverage will usually involve employing solar-thermal energy; apart from energy storage, this will normally also require a reduction in consumption, to make the system economically viable and allow covering the demand with the solar collector space available on site.

Reduction in demand can be achieved by passive and active measures; priority should be given to passive measures, and only the remainder should be reduced by active measures.

While own renewable heat generation typically involves solar-thermal energy technology, it is also possible to employ fuel cells or CHP plants that are powered by non-fossil fuels produced on site, or to use heat pumps that are powered by electricity from on-site renewables.

Means of avoiding fossil fuels are covered in the gasses and fuels chapter.

Figure 8 shows a classification of the various possible steps in the field of gases and fuels.

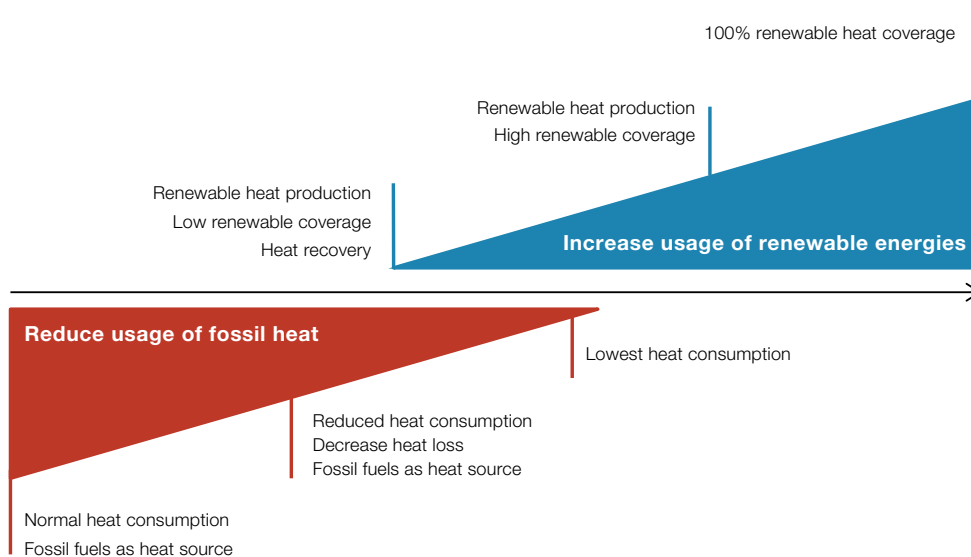


Figure 8: Roadmap for heating systems in C2C-inspired buildings

5.3 Design criteria & boundary conditions

During the definition of the design brief, it is to be defined which degree of coverage of heat from regenerative sources is to be aimed at, and how much of it is to be generated on site; from a C2C point of view, the highest possible degree of coverage is to be aimed at, and at least one type of active regenerative heat generation must be included in the project.

Conflicts of objectives with other C2C aims and the technical necessity of technologies for which there are no C2C alternatives (eg industrial melting processes that cannot yet be carried out regeneratively), economy or space requirements have an influence on the extent to which this criterion can be met, so no generic indication can be given.

For the respective regenerative heat generation, design criteria may have to be defined, eg operating temperatures.

When passive measures are used, their requirements may have to be defined, too – possibly for other designers as well, eg thermal insulation, proportion of glazing, use of roller shutters or window shutters, thermal mass, etc.

The desired thermal comfort criteria are to be defined; it is not sufficient to just specify air temperatures – at least a specification of the resulting (perceived) temperature is required, where appropriate in relation to outside temperature.

Since C2C sets the highest requirements for thermal comfort, all requirements of category A of DIN EN 7730 should be met; in addition, the area of thermal comfort according to DIN EN 7730 must be considered.⁹³

A boundary condition is the use or storage of the excess heat; here it may be necessary to define which conditions apply for feeding into a local or district heating network. If heat generated outside the building is used, the conditions must also be defined for this.

If necessary, other C2C criteria (eg the requirement for an inspiring and safe working environment, materiality and design) may result in further design criteria (eg integration of heating elements, heating of certain functions such as greenhouses); possible conditions for would have to come out of separate guidelines for these applications.

The desired economic efficiency in the implementation of the C2C aim may result in further design values, eg losses in equipment, distribution, etc.

5.4 System selection

During the system selection, it must be established how the desired coverage of regenerative heat production is to be achieved – how is the heat generated renewable, how is it stored?

In the following, possible systems are evaluated regarding their suitability for C2C-inspired buildings.

5.4.1 Passive systems

Passive systems can contribute to a positive heat balance by sustainably reducing heat demand; in extreme cases, they can even make active systems completely obsolete:

In Lustenau, Austria, the office building “2226” was built without heating or other air-conditioning technology⁹⁴. While the necessary boundary conditions (energy density, room height, climatic conditions, surrounding buildings) will not be available in all cases, this can be an incentive to design a building through cooperation with architects and designers that provides a high level of comfort through passive heat gains and storage alone.

The reduction of electrical and heat demand by passive measures makes it easier to achieve a positive energy balance of a building. While passive systems are dealt with in other literature, the most important ones are briefly evaluated regarding their suitability for C2C-inspired buildings in the following paragraphs.

Building shape and orientation: The convective heating demand of a building is significantly influenced by its shape and orientation; a compact design reduces the surface for convection, an orientation of glazed surfaces improves heat gains in winter as well.⁹⁵

From a C2C perspective, these are suitable measures; however, they may conflict with other requirements, eg daylighting, so that this aspect must be considered holistically, involving the entire design team.

Thermal insulation: Efficient thermal insulation of the building envelope also makes a significant contribution to reducing heat requirements; not only the thermal insulation of opaque components is relevant here, but also the proportion of glazing, since glazed components have poorer thermal insulation – an optimised balance of thermal insulation, daylight utilisation and heat utilisation is to be found. Systems that can change the thermal insulation properties of elements during the course of the day or year, such as roller shutters or window shutters, support this aim.

As long as the used materials meet the C2C criteria (this would be covered in the façade design and is therefore not discussed here), the use of thermal insulation is a suitable measure from C2C point of view.

94 Baumschlager Eberle Architekten, n.d.

95 Usemann, 2005, p. 526

Thermal mass: If used correctly, the thermal mass of the building can also contribute to reducing the heat requirement or even to heat production; an example would be the Trombe wall, which functions as a “passive solar collector”, so to speak.

As long as the used materials meet the C2C criteria (this would be covered under facade design and / or architecture and is therefore not covered further in this guide), the use of thermal mass from a C2C point of view is a suitable measure.

5.4.2 Heat generation

The objective of 100% coverage of the heating demand from renewable sources and the associated criteria mean that fossil fuels is not allowed as a source of energy; as a result, installations such as oil or gas boilers or diesel generators cannot be used for this purpose in C2C-inspired buildings – see chapter 4 “[Gases and fuels](#)” for more information on this topic (and on installations with hot combustion).

To generate heat in C2C-inspired buildings, heating concepts must be implemented that include self-generated renewable energy sources; this can also include electric heating systems as long as these are fully supplied with (if possible self-generated) renewable electricity. A percentage of the annual energy consumption must come from self-generated renewable sources; for the rest, “conventional” technology may also be used, as long as the no-go criteria are not violated.

In the following paragraph, some possible technologies are evaluated for their suitability for C2C-inspired buildings.

Image 9: Vacuum tube solar collector and PV panels (Kingspan lighthouse)



Solar thermal: For renewable energy, solar thermal is the preferred method of heat generation from a C2C point of view. This type of energy production is already relatively well-established; this guide will therefore only cover whether there is a preferred solar thermal technology according to C2C criteria.

The main technologies can be divided into non-insulated, insulated and vacuum-insulated collectors. For example, non-insulated collectors are used to preheat water for swimming pools; most flat-plate collectors – the most commonly used technology – are insulated collectors, while vacuum collectors – which are usually only used when high operating temperatures have to be reached – are mostly designed as tube collectors.

A clear tendency as to which technology is most suitable depends more on the application than on C2C criteria; from a C2C point of view, the main factor is the use of materials, in particular the type of coating of the collectors, which is dealt with in chapter [5.6.1 “Heat generators”](#)

Condensing technologies: Due to the hot combustion of gas, condensing boilers are not a suitable technology for achieving the C2C aim of 100% renewable heat coverage – even using biogas or biodiesel. However, if suitable fuels and flue gas treatment are used (see chapter 4 “[Gases and fuels](#)”), their use would not be an exclusion criterion either.

Combined heat and power (CHP) plants: Due to the energy source (only biogas or biodiesel would be acceptable as fuel at all) and the process of hot combustion, CHP plants for C2C-inspired buildings are also only commendable to a limited extent; combined heat and power generation achieves higher energy efficiency, but the energy source and the type of combustion remain a problem. According to the C2C criteria set out in this guide, a cogeneration unit is not a technology that can meet the C2C heat positivity aims on its own. However, if suitable fuels and exhaust gas treatment are applied (see chapter 4 “[Gases and fuels](#)”), its use would not be an exclusion criterion, either.

Fuel cells: An alternative to condensing technologies would be fuel cells, which do not produce carbon monoxide or fine dust, because of their cold combustion using hydrogen; the as a result, their exhaust gases can be used more easily as a nutrient for green areas in buildings.

Unfortunately, the fuel cells currently available on the market are powered by natural gas, an energy carrier with limited usability in C2C-inspired buildings; pure hydrogen operation is not yet possible. The plant sizes available on the market are also more suitable for single-family homes than for larger customers.

The technology of fuel cells and their suitability for C2C are described in more detail in the chapter 8.4.2 “[Electrical storage](#)”; further information on the use of gas as a fuel can be found in chapter 4 “[Gases and fuels](#)”.

Heat pumps: Heat pumps as a technology can – as long as they are operated with renewable electricity – make a contribution to the C2C aims; ideally, the plant is operated with self-generated electricity from renewable energy. It is important to ensure that the technology operates as efficiently as possible, for example by selecting and calibrating the supplied systems (heating, cooling; operating temperatures) accordingly.

Which heat source (air or geothermal heat) should be favoured from a C2C point of view could not be clarified during the preparation of this guide, and will mostly depend on other project-specific boundary conditions (eg project programme, geometry of plot and building). When using geothermal energy, the effect of the heat extraction (thermal effects on the groundwater) as well as the materiality and the used substances must already be taken into account during the approval process; this technology should only be used if this does not entail any risks for the environment and if there are no other renewable variants.

Another point to note from a C2C point of view is the use of the refrigerant. Currently, there is no refrigerant optimised for the biological cycle; this means that the refrigerant must be optimised for the Technosphere.

Refrigerant recycling systems already exist for this purpose and the take-back is regulated by regulations, so that it can be processed to the same quality or the chemical ingredients can be recycled in other applications; this means that refrigerants can be used in C2C-inspired buildings. Nevertheless, refrigerants remain hazardous substances that must not be released into the environment (use of drip pans, alarms in case of pressure drop) and whose use should be minimised (eg avoidance of VRV/VRF systems).

Further information on refrigerants can be found in chapter [7.5.2 “Refrigerants”](#).

District and local heating network: Heat from district or local heating networks can in principle be used in C2C-inspired buildings; however, the type of heat source used by the provider must be considered: From a C2C perspective, district or local heating is only really considered renewable if the heat sources are powered by renewable energy.

In Berlin, for example, Vattenfall feeds the waste heat from coal and gas-fired power plants into the grid; this allows more efficient use of resources, but its source is still a fossil fuel, and the use of heat from such energy sources would not be in line with C2C. The same applies to heat from waste incineration plants.

District heating from such sources would therefore not be suitable for achieving the C2C aim of 100% renewable heat coverage; however, the use of district heating with a primary energy factor of 0 (with the exclusive use of waste heat from other processes) would not be regarded as a no-go criterion, either.

For district and local heating networks that are operated using biogas to generate electricity, the C2C criteria for biogas are also required, see chapter [4 “Gases and fuels”](#).

Waste heat utilisation: Following the logic applied for district heating, the use of fossil process heat from industrial applications is also incompatible with the objective of C2C and would not count towards achieving a 100% renewable heat coverage; however, it would not be taken as a no-go criterion, either.

When using waste heat from refrigeration processes in buildings, the energy source used for the latter would be important: In chillers operated with regenerative energy, this waste heat could contribute to a 100% renewable heat coverage, in absorption refrigeration plants it would depend on the energy source (steam from fossil processes would not be usable, wind gas would be, etc.).

In principle, however, the idea of using waste heat is to be welcomed for reducing the heat requirement of the building and increasing the degree of coverage of regenerative heat production.

5.4.3 Heat storage

When using energy sources that are not permanently available, such as solar energy, it will be necessary to use heat storage systems. C2C does not initially prefer any particular heat storage technology; it is also up to the designer to decide whether the storage tank is to be used in combination with domestic hot water preparation heating or not.

For all storage tanks with water as storage material, the insulation material and the pipes in the storage tank must be designed according to the C2C criteria according to the usage scenario (contact with water and heat) (see also chapter 3 “Water systems”).

In the following, storage tanks are examined regarding their suitability for use in C2C-inspired buildings.

Buffer storage: Due to their typically metal construction, good recyclability is guaranteed; care must be taken to optimise insulation according to C2C requirements – see subsection 5.4.3 “Heat storage”. Information on the C2C suitability of seals is not yet available.

Latent heat storage: Latent heat storage is a special form of thermal buffer storage; although water is also used for heat storage, they either use it as a phase change medium, or substances such as salt hydrates or paraffins are added. The latent heat accumulator uses the latent heat of the transition between the solid and liquid state of the substance (water or mixture) at the temperature level of the tank.

In the case of ice storage, latent heat from water is used. Plastic pipes containing a water/glycol mixture are passed through the storage tank; this mixture circulates in the pipes and withdraws energy from the storage. This energy can be used for a longer period of time and thus supports the use of renewable energy.

Information on the evaluation of the materials used can be found in chapter 5.4.3 “Heat storage” and in chapter 5.6 “Material selection”. In general, the use of latent heat storage can be achieved meeting C2C criteria; however, this requires some modifications to “off-the-shelf” systems.

Image 10: The new Rijksmuseum, Amsterdam, uses an aquifer for seasonal heat storage



Seasonal heat storages: From the C2C point of view, seasonal heat storages such as those used, for example, in the Sonnenhaus Institute's⁹⁶ solar houses can be regarded as similar to the smaller buffer storages; they support a renewable energy concept, but due to their size can have a considerable influence on the architecture – here, early consultation of the various disciplines is crucial.

Two special forms of seasonal heat storages are geothermal fields and aquifer wells. In the case of geothermal fields, heat is stored in the ground in summer, which is called up again in winter; in the case of aquifer wells, heat is stored in deep, non-flowing groundwater, where normally two wells – one warm and one cold – are used.

In both cases, care must be taken not to contaminate the soil or groundwater; however, they are generally suitable for C2C-inspired buildings, as long as the C2C criteria are observed in the materials used for the pipes, ground piles and heat exchangers.

It is also important to consider the space requirements, which will not make these systems suitable for all buildings.

Night storage stoves: A night storage stove only makes sense as an electric heater if it is operated with renewable electricity generated by the user.

5.4.4 Heat distribution network

The heat distribution networks differ in principle only in the material selection; see the corresponding subchapter [5.6 “Material selection”](#) in this chapter.

5.4.5 Space heating

From a C2C point of view, there is no clearly favoured technology for space heating; all systems have different advantages and disadvantages and must be assessed individually for each project.

In general, systems should be selected to allow or support the use of regenerative heat generation; this will require low operating temperatures, depending on the system selection for heat generation.

A further principle is that user comfort in the sense of C2C should be set higher than material consumption, as long as suitable materials are used for C2C use. The design can also be a decisive factor in the choice of system (recyclability) – see relevant chapters.

The different modes of action of the technologies and their efficiency were not assessed; in this guide the technologies are only evaluated regarding the C2C aims and the C2C criteria of heat generation.

Free-standing terminal heating devices (radiant panels, radiators or convectors): An advantage of radiators is the usually easy accessibility (ease of disassembly) as well as the use of steel or metals as base material (good recyclability); however, the paints and alloys used are not yet recyclable, which should be taken into account when choosing the product.

A disadvantage of radiant panels is that they often do not support regenerative systems due to their comparatively high flow and return temperatures.

Integrated terminal heating devices: Due to their low flow temperatures (usually < 40°C), surface heating systems are very suitable for regenerative heating systems (geothermal, solar thermal); it is up to the designer to decide whether to install floor, wall or ceiling systems.

However, it is important to ensure that the type of construction allows a full recycling of the employed material, and that the pipe material is recyclable; thermal comfort must also be taken into account. Casting pipes into the concrete or the screed excludes this type of construction for a C2C-inspired building.

Underfloor and wall heating can be installed either as a wet or dry system. In C2C-inspired buildings, only dry systems can be used, as the casting-in of pipes (wet system) means that dismantling or maintenance work is no longer possible or at least significantly more difficult; this also applies to activated thermal mass systems. In this case, the recyclability of the material has a higher priority than any advantages in energy consumption.

The method of installation is also crucial for ceiling heating systems; if pipes are plastered or even embedded in concrete, this leads to downcycling of the material, so that radiant panels or cavity ceiling heating systems⁹⁷ are preferable from a C2C point of view. This also applies to combined heating and cooling ceilings.

Cavity ceiling heating systems are installed between the load-bearing ceiling and the suspended ceiling; this allows good maintenance and thus leads to good dismantlability.

It should generally be noted that heating from the ceiling is less energy efficient (due to thermal stratification) and leads to lower thermal comfort (warm feet and a cool head are desirable for comfort); in principle, floor or wall heating would be preferable from a C2C point of view, but only if dry systems are used.

Infrared heaters: Infrared heaters are electrically operated and allow very flexible installation; so-called heating fleeces can be relatively easily adapted to the new conditions after a refurbishment. Some infrared heaters run on direct current, which also allows them to be connected to a low-voltage network in the building.

To be used in a C2C-inspired building, the heaters must be supplied with electricity (preferably generated by the building itself) from renewable sources. The manufacturers still are currently not able to provide sufficient information on the recyclability of the systems, so that they cannot be finally evaluated at present.

In the case of a power supply from purely regenerative sources, infrared heaters can be a good alternative to conventional room heating elements as soon as their recyclability can be confirmed.

5.4.6 Air heating

In the case of mechanical ventilation, the outside air has to be preheated under normal circumstances; in the case of modern office buildings which meet high thermal insulation requirements, the heating loads are so low that they can possibly be completely covered by mechanical ventilation.

Heating is usually provided by heating coils in the central ventilation units (although the assessment also applies to terminal units); these can be heated with water, refrigerant or electrically.

Water comes from the same circuit as for the heating elements mentioned above, so the same requirements apply; for the use of refrigerants, see the corresponding remarks in chapter 5.6.1 “Heat generators”. Electric heating registers can in principle be used, but only if the electrical energy comes entirely from regenerative sources that are generated as far as possible by the user.

5.5 System sizing

As soon as the systems are selected in accordance with the C2C aims, the usual specifications of the system design, as well as the design criteria defined under “Design criteria and boundary conditions” (in particular the solar coverage of the various systems) apply; in contrast to the design of conventional systems, the annual energy demand (ie not just the peak load) must be determined as well.

When designing the systems, attention should be paid to the reduction of energy consumption; the system should be designed for supplying the minimal demand, to avoid unnecessary material consumption by unnecessarily large central plants or networks; this also increases the technical feasibility of a 100% renewable heat coverage.

However, in this process the full lifecycle of the equipment should be considered; if it is likely that the heating demand changes during the lifecycle of the equipment, the possible range throughout the lifecycle should be considered, to avoid having to replace equipment before the end of its lifecycle.

When reducing consumption, passive measures (building shape & orientation, thermal insulation, thermal mass, etc.) should be prioritised over regenerative heating technologies.

Space requirements will play an important role in designing solar-thermal systems; to give a feel for it, some typical data on energy generation from solar collectors per m² per year:

350 kWh/m²a Glazed flat plate collectors⁹⁸

450...550 kWh/m²a Evacuated tube collector⁹⁹

When solar energy is used, the adequate design of the heat storage system will play a major role in the desired operation of the building, for which a detailed energy requirement calculation and system design will be necessary.

Viessmann type ES-B 10 can be cited as an example of the size of a latent heat storage unit; with a heating capacity of 10 kW, it has a water volume of 10 m³, equivalent to about 1,150 kWh (depending on operating temperatures). A practical example is also the Kampa GmbH construction project, in which ice storage tanks with a volume of 683 m³ were installed for a heating system with 3 heat pumps and a combined heating output of 119 kW.¹⁰⁰

Seasonal heat storage tanks with water as a storage medium begin to be energy-efficient when the storage volume 1,000 m³, when the heat losses reduce due to the improved ratio of ratio of volume-to-surface. Built tank heat storage tanks range from 2,750 m³ to 12,000 m³.¹⁰¹

See chapter 8 “Electrical installations” for dimensions of fuel cells.

98 UK Department for Business, Energy and Industrial Strategy, n.d., p. 7

99 UK Department for Business, Energy and Industrial Strategy, n.d., p. 9

100 Viessmann AG, n.d.

101 Steinbeis Forschungsinstitut für solare und zukunftsfähige thermische Energiesysteme, n.d.

There are no C2C-specific dimensioning criteria for heat distribution networks; the networks should in principle be optimised for reduced material consumption, although in the case of conflicts between the size of the pipes and the pump capacity, it may be beneficial to design them for a lower pump capacity to achieve a smaller pump size.

The latter depends strongly on the energy concept and must be checked individually for each project; where the supply with regeneratively produced electricity cannot be guaranteed in winter or is < 100%, the energy consumption would take precedence over the material consumption, as long as materials suitable for C2C usage are used in the pipe network.

5.6 Material selection

As far as materials for the equipment are concerned, there is currently little possibility of insisting on *Cradle to Cradle Certified*TM or similar materials, manufacturing processes or biodegradability due to the market situation; however, it will help the market spread of the concept to approach the manufacturers in each case – this may initiate a rethinking process. It would probably also help if MEP designers cooperated with manufacturers to review and pilot (even if only in a part of the installation) C2C-inspired products – this could lead to a rethinking and the development of new products, materials, or construction methods.

5.6.1 Heat generators

Solar thermal energy: In principle, it is possible to recycle solar thermal systems, although the quality of the recycling is currently not clear. A return of the collectors by the manufacturing companies is regulated, for example, by the Blue Angel (“Der Blaue Engel”) standard in Germany. This standard distinguishes solar collectors with a particularly high energy output; in addition, the heat transfer medium and insulating materials cannot contain any halogenated hydrocarbons as these substances damage the ozone layer.¹⁰²

Flat-plate collectors are generally less technically complex than vacuum tube collectors and therefore easier to recycle; the materials used (glass, aluminium, rock wool) are in principle recyclable. For glass, coatings (usually titanium oxide, black nickel or black chrome) have to be evaluated, as this means increased recycling costs; however, since they contribute to the efficiency of the solar collector and the materials are not on the “Banned List” of the C2CPII, they are not a no-go criterion.

For the heat transfer medium, which usually consists of a water/glycol mixture, there are recycling measures that can process the mixture by distillation and thus enabling recycling of the glycol.^{103,104}

At the time of writing, there are no *Cradle to Cradle Certified*TM or C2C-inspired solar collectors.

Fuel cell: At the time of writing, there are no fuel cells that are *Cradle to Cradle Certified*TM or with equivalent materials; for further information, see the corresponding subsection [8.4.1 “Electricity generation”](#).

Heat pump: When selecting the heat pump, particular attention must be paid to the refrigerant; it should be ecological and adhere as close as possible to C2C criteria. Since there is not “the one” refrigerant for all applications, a clear statement on which refrigerant is most suitable could not be carried out in the scope of this guideline; upcoming regulations will also likely change the market substantially, so an evaluation of the new refrigerants will become necessary.

At the time of writing, there is no heat pump manufactured with *Cradle to Cradle Certified*TM or equivalent materials. Further information on refrigerants can be found in chapter [7.5.2 “Refrigerants”](#).

102 RAL gGmbH, n.d.

103 ENTEK GmbH & Co. KG, 2016

104 SET Schröder GmbH, 2017

5.6.2 Heat storage

At the time of writing, there was no heat storage unit made of C2C-inspired materials or of equivalent quality available in the market.

Storage tank material: Most buffer tanks are made of steel, but there are also tanks made of GRP or plastic. Corrosion is unusual in buffer tanks for heating systems, which is why steel is typically used without enamelling; domestic hot water storage tanks are made of steel with coatings of enamel or plastic as corrosion protection.

Enamel is generally a mixture of different metal oxides. These metal oxides are mixed differently depending on the application, colour and manufacturer. A recycling of these materials into their components or into new enamel is not possible. For this reason, enamel is not suitable for C2C at present.

A plastic coating of the storage tank poses the same problems as the coating with enamel – separation by type during recycling and processing of the plastic is extremely unlikely.

Information on storage tanks made of plastic can be found in chapter 3 [“Water systems”](#).

GRP storage tanks are not recommended according to C2C criteria, as GRP is a composite material that so far cannot be recycled by material type.

According to C2C criteria, only storage tanks made of stainless steel are currently recommended, as these have the best recyclability.

Insulation: The main difference to drinking water storage tanks is the insulation; it is either made of soft foam material, mineral wool or polyurethane (PUR).¹⁰⁵

For the evaluation of insulation materials see chapter 3 [“Water systems”](#); the materials listed there are only evaluated here for suitability for heat supply systems, and some other materials which are not listed there are considered as well.

PUR is not a solution suitable for C2C – see explanations under chapter 3.6.10 [“Pipe insulation”](#).

An application of calcium silicate as insulation material for buffer storage tanks is not yet known, but would be suitable.

Mineral wool is suitable under certain conditions – see explanations in chapter [3.6.10 “Pipe insulation”](#).

Polystyrene is also petroleum-based; it is not recyclable and contained toxic flame retardants for a long time. Even if these are no longer permitted, the problem of impossible recycling and with flammability remains. Polystyrene is therefore not a C2C material in the current version.

Cradle to Cradle Certified™ (Gold level) seaweed insulation from Advance Nonwoven A/S could be used as an alternative to the above materials.

As a further alternative, ecological insulating materials such as stuffing hemp can be used¹⁰⁶ - see explanations in chapter [3.6.10 “Pipe insulation”](#).



Image 11: Seaweed insulation from convert

External lining: For the external lining of the storage tanks, PVC is used for example by Jenni and Twl Technologie, which is not suitable according to C2C criteria (is on the “Banned List” of the C2CPII); an encapsulation with polystyrene, such as used by Forstner and Soleado, also does not meet the C2C criteria, either. As an alternative, galvanised sheet steel can be used.¹⁰⁷

Latent heat storage: The storage container is usually either made of concrete (eg Viessmann) or plastic (eg PE from Calmac). The use of concrete makes the storage facility difficult to commend according to C2C material criteria; whether the use of the plastic fulfils C2C criteria would have to be checked in a material analysis – ideally the containers would be made of metal.

The most typical storage media for latent heat storage are salt hydrates and paraffins.

In the case of salt hydrates, the assessment for C2C-suitability depends on the salt hydrate used¹⁰⁸; the frequently used sodium acetate trihydrate can at least be classified as non-toxic.¹⁰⁹

According to the research carried out during the preparation of this this guide, paraffins are generally considered non-toxic¹¹⁰, so at least their use is not a no-go criterion; their flammability should be taken into account in the fire safety concept.

In addition to toxicology, other criteria must also be considered for C2C, such as recyclability. No further information is currently available on either of these media.

In addition, the material of the pipes (eg Viessmann type ES-B 10 PE pipes) and the water/glycol mixture (see information in chapter [5.6.1 “Heat generators”](#) under heat pump) must be optimised according to C2C criteria.

106 Hanffaser Uckermark eG, n.d.-b

107 Albers et al., 2015, p. 768

108 Bayerisches Zentrum für angewandte Energieforschung e. V., n.d.

109 Carl Roth GmbH, n.d.-b

110 Carl Roth GmbH, n.d.-a

There are recycling measures for the heat medium, which usually consists of a water/glycol mixture, which can process the mixture by distillation and thus enable the glycol to be recycled.^{111,112}

The materials used potentially cancel the positive effect for the use of renewable energy; in the case of a planned use, it would have to be checked whether the tank and pipe materials could be modified (eg stainless steel tank and metal pipes).

5.6.3 Heat distribution

Piping: At the time of writing, there are no *Cradle to Cradle Certified*TM heating pipes available. Based on the research carried out in this guide, metal pipes are preferable due to their recyclability.

There are heating pipes made of steel or copper; both types of metal have different advantages and disadvantages, which are dealt with in the chapter [3.6.8 “Domestic water pipes”](#). Both can in principle be used in C2C-inspired buildings; a clear statement as to which metal is better according to C2C criteria could not be made.

For plastic heating pipes, usually PE-RT or PE-X are used, but also PP (PPR, PPR-CT and PPR-FR) are getting more market share.

Pipes with PE-RT (heat-resistant PE) are produced in various forms (3-layer¹¹³ or 5-layer¹¹⁴); they always contain an EVOH (ethylene-vinyl alcohol copolymer) layer and so-called adhesive layers. Information on the recycling of this material has not yet been found; however, it can be assumed that only downcycling is possible due to a material mix that cannot be separated any more.

Pipes made of cross-linked PE (so-called PE-X) cannot yet be recycled to the same quality.¹¹⁵

Both PE-RT and PE-X pipes have so-called composite pipes in which an aluminium layer is integrated; this also makes recycling more difficult, meaning that these pipes do not meet the C2C criteria.

Similar to the PE pipes, PPR pipes are multilayer, high temperature (PPR-CT) and glass-fibre reinforced pipes; their recyclability is similar to that of the PE pipes.

Both materials should therefore not be used in C2C-inspired buildings.

Pipe insulation: Thermal insulation contributes mostly to energy efficiency; for C2C energy efficiency is only a means to achieve the highest possible coverage of consumption by renewable energy, though. Still, pipe insulation reduces material in the heat generation, so the additional material for insulation still make sense from a C2C point of view.

Pipe insulation for heating water differs only insignificantly from pipe insulation for hot water; please refer to the corresponding subchapter [3.6.10 “Pipe insulation”](#). When

111 ENTEK GmbH & Co. KG, 2016

112 SET Schröder GmbH, 2017

113 PELIA Gebäudesysteme GmbH, n.d.

114 Becker Plastics GmbH, 2015

115 Avraam & Keyuan, 2014

insulating heating pipes, the aptness of the insulation to perform at higher temperature will have to be considered in addition; differences to drinking water insulation are described below.

PE insulation can only be used up to a temperature of 100°C; this may have to be observed when using vacuum collectors.

For rubber insulations, the permissible temperature range must be observed; there are special products for solar systems.

Pipe fixings: For fixings of heating pipes, the same applies as for fixings of drinking water pipes; please refer to the corresponding subchapter [3.6.11 “Fixings \(pipe clamps and mounting elements\)”](#) in the chapter [3 “Water systems”](#).

Fittings / Installations: Installations such as pumps, mixers, valves, thermostats, ball valves, butterfly valves, gate valves, venting devices and dirt traps must also be optimised in accordance with C2C criteria. Since the construction method corresponds in principle to that of installations in drinking water systems, reference is made to the corresponding chapter.

5.6.4 Space heating equipment

At the time of writing, there were no terminal heating devices that are *Cradle to Cradle Certified*TM or consist of C2C-inspired materials.

Radiators: Free-standing radiant panels or radiators are usually made of sheet steel with acrylic or synthetic resin coatings; in individual cases, they are also made of cast iron or aluminium.^{116,117} These metal radiators tend to be recyclable; the quality of recycling depends on the quality of the metal and the applied paints.

At the time of writing, there are no *Cradle to Cradle Certified*TM radiators; an assessment of which radiators better meet C2C criteria is not yet possible due to the difficult data situation.

Coatings: Due to the heat development of the radiators, the heat resistance of the coatings plays a decisive role¹¹⁸; special heat-resistant acrylic or synthetic resin paints are used to paint the radiators.

Coatings are generally extremely critical according to C2C criteria, as they can reduce the material quality of the recyclate; but above all, there is currently no information as to whether they can be collected again during the recycling process in their pure form – they are converted into a slag that can no longer be used.

For this reason, paints should generally be avoided as far as possible in C2C-inspired buildings. However, this is difficult to implement for radiators; here, at least, attention must be paid to the use of solvent-free paints and paints bearing the Blue Angel label.

Synthetic resin coatings contain a higher proportion of organic solvents and thus a higher VOC concentration than acrylic coatings;¹¹⁹ acrylic lacquers are therefore

116 Albers et al., 2015, p. 797

117 Krimmling et al., 2014, p. 57

118 Alpina Farben GmbH, 2017

119 Umweltbundesamt, 2012, p. 8

preferable to synthetic resin lacquers. However, acrylic lacquers also contain organic solvents and should therefore be used as little as possible – ideally, radiators were left unpainted /-coated.

Ceiling radiant panels: Ceiling radiant panels usually consist of steel sheets, pipes are welded on or attached with clamps. Clamps are to be preferred according to C2C criteria in chapter 14 “[Construction Methods](#)”. For coating, the same comments apply as for radiators.

Cavity ceiling heating: The design of cavity ceiling heating systems is similar to that of radiators; here, the use of metal as a material is also to be rated positively, while the suitability of the paints or alloys used is questionable.

Underfloor heating systems: As already stated under “System selection”, in C2C-inspired buildings underfloor heating systems can only be installed in a dry system, as the casting-in of pipes in wet systems makes dismantling or maintenance work no longer possible or at least considerably more difficult; this applies accordingly to activated thermal mass systems.

For underfloor heating systems, typically plastic pipes are used, which are not suitable for C2C; more detailed information on the PE-RT and PE-X pipes can be found in chapter 5.6.3 “[Heat distribution](#)”. Systems with copper pipes are also available; these are to be preferred according to C2C criteria, as the plastic pipes are not yet recyclable under C2C criteria.

At the time of writing, there are no *Cradle to Cradle Certified*TM floor, wall or ceiling heating systems.

Heating coils: Heating coils are available in various designs and material compositions. Manufacturers offer the various components such as housings, fins, tubes in various metal designs (eg copper, aluminium, stainless steel, pre-painted fins). The choice of material depends strongly on the application; however, copper tubes are usually used in conjunction with aluminium fins.

In general, metal is easily recyclable (without painting or coating). Whether the heating elements, which are composed of different types of metal, are suitable according to C2C criteria depends strongly on the type of connection used between the tubes and the fins; this must be reversible according to C2C criteria and function without reducing the material quality. In most cases, the tubes are pressed or soldered to the fins; according to C2C criteria, press joints are to be preferred as no solder has to be used. If there are plugged or screwed variants, these are also to be preferred.

A mono-material solution (eg copper tubes and fins) facilitates the recycling process and is therefore preferable.

Infrared heaters: Infrared heaters can be fabricated as carbon fibre heating fleeces (IR-CNT) or with heating wires.

It is not yet possible to make a statement on the recyclability of IR heating fleeces; in the literature, only the CO₂ balance has been discussed in the field of ecology and the debate has been conducted as to whether electricity should be used as a heat source – a discussion of the materiality and recyclability has not yet been addressed.^{120,121}

From a C2C point of view, when using IR heating, the type of installation must also be considered. Casting-in or integration into a component creates a non-detachable connection or one that can only be separated by destruction; this does not make recycling to an equivalent quality possible. Flexible installation on the wall or other building elements is more in line with the C2C criteria.

120 Kosack, 2009

121 Prof. Dr.-Ing. Meier, 2006

5.7 Construction methods

When installing heat supply systems, care must be taken to ensure that the pipes of the systems are not cast in; this makes a disassembly process for repair or recycling more difficult and reduces the value of the material and leads to increased waste production.

The pipe connections must also be as easy to dismantle as possible; this facilitates the re-use of the material and keeps the value (financial and material-related) of the component high for a longer time. As a result, welding, soldering etc. should be avoided as far as possible – separable connections such as screw or press connections are to be preferred.

There are currently only a few *Cradle to Cradle Certified*TM components or components manufactured according to similar criteria in the field of heat supply systems. For this reason, the choice of construction method can represent a first step and can increase the pressure on manufacturers in the planning stage by asking to what extent individual parts can be replaced and whether components can be separated by sort according to C2C criteria.

6. Ventilation systems

6.1 Aims and evaluation criteria

6.1.1 Overview

C2C aim	Positive oxygen balance Indoor environment contributing to wellbeing
C2C minimum criteria	Healthy indoor air (measurement of indoor air quality during operation) and neutral exhaust air (measurement of outdoor air quality before construction, measurement of exhaust air quality during operation)
C2C no-go criteria	Harmful exhaust air and unhealthy indoor air
C2C material criteria	See chapter 13
C2C construction methods	See chapter 14

6.1.2 Explanation

The aim of a C2C-inspired building is to produce more oxygen than it consumes, clean the outside air, and to provide an indoor climate that contributes to the wellbeing of its inhabitants. With a C2C-inspired building, the air quality at the building's location should be better instead of just less poor. A positive oxygen balance would mean that the building – including its operational processes – is producing more oxygen than it is consuming. From a C2C point of view, a biological production of oxygen makes sense (the technical expenditure for oxygen production should be as low as possible), but it falls within the responsibility of other disciplines (eg landscape designers or facility managers).

Which indoor environment contributes to wellbeing is difficult to define, in particular related to air – health and wellbeing are influenced by so many factors that it is difficult to quantify. The criteria of the WELL certification offer a viable approach, going beyond a pure definition of air volume and quality.

Harmful exhaust air can be defined more easily: Relevant air pollutants have been defined by the WHO. Harmful exhaust air would be considered to have a higher pollutant load than ambient air prior to the construction of the building. Neutral exhaust air would have at most the same degree of pollutant load.

In the sense of the C2C mindset, air humidity is initially not regarded as a pollutant in the assessment; increased exhaust air temperature would only be considered a 'pollution' where it is caused by energy consumption in the building (ie not from human metabolism or solar heat gain), which is covered in the corresponding chapters (eg "[Heating systems](#)" and "[Electrical installations](#)").

Ventilation systems can only influence how the air flows through the building, control its distribution, and filter it. However, the largest influencing factor for the air quality are the materials and products used in the construction as possible sources of pollutants, as well as greening of the building to filter CO₂ and produce oxygen.

This highlights that wellbeing and air quality are interdisciplinary topics that affect several disciplines (eg architecture, facade design, landscape design) and can only be solved in cooperation. However, this guideline only deals with topics that can be influenced by ventilation system designers – it is assumed that other measures such as greening (eg green facades and roofs) are covered in guidelines for the relevant disciplines.

Figure 9 gives an overview of the different stages of air passing through a building,

Figures 10 shows the different components of a ventilation system and their influencing factors.

Figure 9: Overview air system

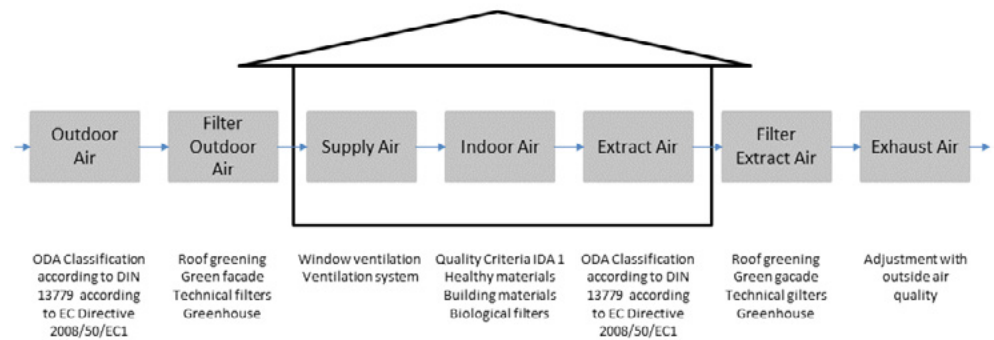
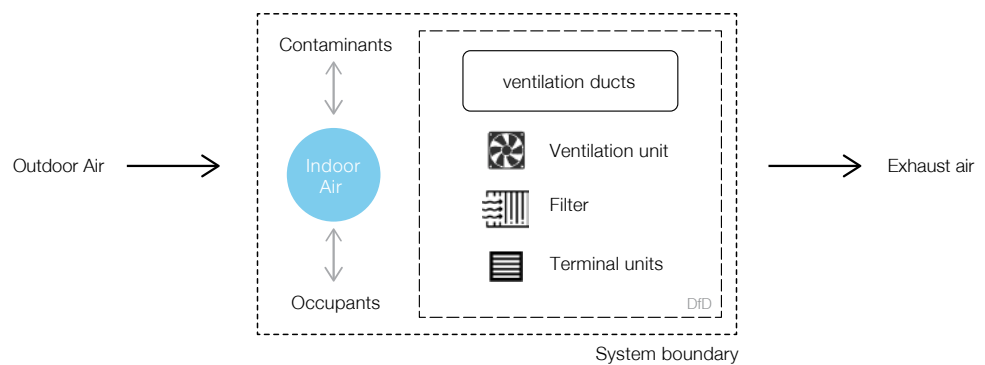


Figure 10 gives an overview of the ventilation system in C2C-inspired building.

Figure 10: Overview ventilation system



6.2 Means of implementation

Achieving a positive oxygen balance or an indoor environment that contributes to wellbeing will require greening both the outside and the inside of the building; as this is usually part of the architect's, the façade consultant's or the landscape designer's scope, the contribution of the building services designer consists in 'reducing the burden' by providing sufficient outside air and avoiding contamination.

Providing sufficient outside air is mostly a matter of system sizing; as it increases plant space, it needs to be coordinated carefully with the other design parties.

Avoiding contamination includes both air supply and exhaust air; both have an impact on space uptake and energy consumption, and again required careful coordination with the other design parties – while improved wellbeing is considered more important than energy consumption, ideally the additional energy would be from regenerative sources.

The way to achieve this is shown in Figure 11 as a roadmap for ventilation systems.

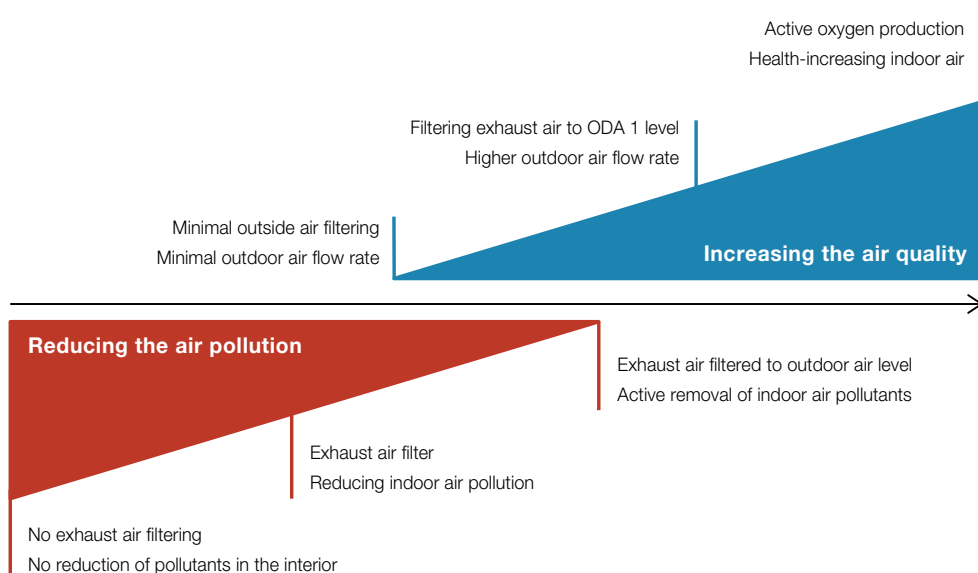


Figure 11: Roadmap for ventilation systems in C2C-inspired buildings

6.3 Design criteria & boundary conditions

6.3.1 Healthy indoor air

For indoor areas, the quality of indoor air must be defined. According to C2C, a healthy indoor climate is to be created, but there are still no clear C2C definitions for this; in their absence, this guideline refers to existing codes and regulations, for which the highest quality requirements must be achieved in each case. This means:

- IDA 1 according to EN 13779 for non-residential buildings
- Category A according to EN 7730 for residential buildings
- Thermal comfort according to EN 7730¹²²

The use of the criteria from WELL certification¹²³ or the DGNB certification is also recommended; it should be noted, though, that some of these criteria go far beyond the areas of influence of a ventilation system designer and can only be achieved in cooperation with the entire design team.

Ventilation systems influence the quality of indoor air by controlling the volume of outdoor air supplied, its temperature, and its humidity, and by filtration. These conditions are to be specified in brief, as well as criteria for the thermal and acoustic comfort of the occupants in the spaces.

In addition to the design of the MEP installations, building materials, finishes and furniture have an influence on the indoor air quality; however, their selection is typically not the responsibility of the ventilation system designers. The MEP designer should make the other designers aware of the importance of the building materials and the need to optimise them according to the C2C design concept. It should also be stated whether a smoking ban is assumed for the building, and within which distance from the building (like mentioned in WELL certification Air feature 2 part 2).

In addition to air quality, the possibility of occupant control of the mechanical and natural ventilation systems also has an influence on well-being; this should also be stated as a design criterion.

6.3.2 Neutral exhaust air

In contrast to conventional buildings, C2C-inspired buildings must also control the quality of the exhaust air. To have a positive oxygen balance, the exhaust air quality must be better than that of the outside air; as a minimum criterion, the exhaust air may not be more polluted than the outside air.

In order to define how much filtration of the exhaust air is necessary, the ambient outdoor air quality must be analysed prior to construction. The results of the measurement would determine which filter class or which type of active treatment the exhaust air receives so that it has at most the same pollutant load as the outside air.

In addition to the pollutants mentioned in DIN 13779 (sulphur dioxide, nitrogen dioxide, benzene, carbon monoxide, lead, fine dust), odorous substances (eg chlorine from swimming pools, odour-intensive substances from production) must also be taken into account; the odour quality of the ambient air compared to that of the ambient air prior the construction must be improved.

In this context, moisture (as relative humidity) or carbon dioxide (CO₂) generated by the building occupants are not regarded as pollutants according to C2C-Criteria – the logic being that it would also be produced if the occupants sat on the plot without the building.

To establish if a building has a positive oxygen balance, the system boundary would be set at the boundary of the site and outside the building (a distance away from the building envelope) and take into account the positive effects of greened areas.

6.4 System selection

C2C does not call for a particular type of ventilation type or technology; the aim is to achieve the defined aims as far as practically possible for every project.

The topics air comfort and air quality (and the influencing factors) are already extensively covered in research papers and publications; this guide only focuses on technologies or measures which have a positive effect on the C2C-specific criteria.

6.4.1 Type of ventilation

In principle, C2C does not favour naturally or mechanical ventilation – the system simply has to be apt to fulfil the aim of healthy air quality and good indoor climate.

While natural ventilation is a viable ventilation strategy for some building types, its design is the responsibility of the architect and not covered in this guide. In principle, natural ventilation would be preferable wherever possible, as it tends to have lower embodied and operational energy use; however, depending on the building usage and external factors, it can be challenging to meet indoor comfort criteria (thermal, acoustic etc.).

In the case of mechanical ventilation, a fundamental differentiation would have to be made between displacement ventilation and mixed-mode ventilation; from a C2C point of view, displacement ventilation would in principle be preferable due to the lower turbulence of pollutants, but this is very case-dependent and C2C does not generally predefine a specific type of mechanical ventilation.

6.4.2 Mechanical ventilation systems

While the C2C criteria do not favour a particular ventilation system, they influence their elements and functions:

- It must be possible to filter the supply and exhaust air.
- The systems should allow variable volume flow control to control the high required air volumes according to real demand / occupancy.

6.4.3 Filtration

The type of filter system depends on the required filter class. In principle, it is permissible to use commercially available mechanical filter systems for C2C-inspired buildings – considering the criteria specified in chapter 13 "Material" for the filter.

Activated carbon filters (see chapter 6.6.6 "Filters") or air washers (see chapter 6.6.5 "Air washers") may be required to meet necessary air qualities.

Green roofs or facades can also be used as air filters; however, their design is often not within the responsibility of the ventilation system designer and is therefore not dealt with here. However, the ventilation system designer should consult with the relevant designers of other disciplines to make use of synergy effects; for example, supply air intake in green areas would be recommended, and exhaust air routing via greenhouses could be regarded as a possible system choice in a broader sense.

Two possible strategies for a positive oxygen balance:



Image 12: Green building envelope (Singapore school of the Arts)

Roof and façade greening: In the Venlo Municipality building in the Netherlands, outside air is drawn through oxygen-producing plants into the respective rooms. However, it is difficult to quantify the benefit of this strategy as there are at present no guideline values for the influence of a m² green façade on air quality, as it depends on many factors, such as the choice of plants, time of day and season, and weather conditions.



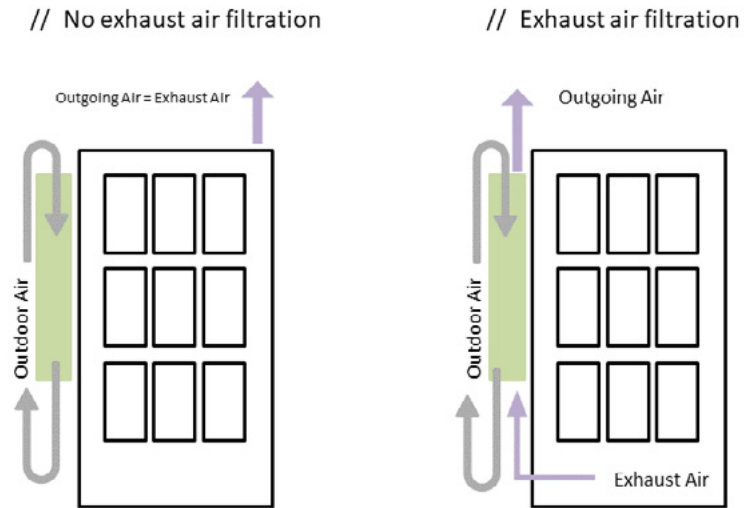
Image 13: Inside the Dachfarm building, Berlin



Greenhouses: The exhaust air from the interiors can also be drawn through greenhouses. Here, the high CO₂ content serves as a nutrient for the plants, which enables a nutrient cycle within the building; the plants also serve as a filter for the exhaust air. This effect is already being used in pilot projects (eg “Dachfarm Berlin”).

The link between greenhouses and buildings currently focuses on an analysis of energy savings, heating and the positive effects on the water cycle; the benefit to the air quality and well-being still requires further investigation and a higher awareness of the topic.

Figure 12: Green facade with and without exhaust air filtration



In industrial facilities, typically special filters are required, depending on the specific application (eg in a paint shop), but these represent a special case which is not covered in the scope of this document.

6.4.4 Air distribution

In principle, C2C criteria have no influence on the air distribution (with the exception of the choice of material); however, elements for controlling the air flow rate may have to be taken into account.

The air distribution in the room must be suitable for creating draught-free air circulation and meeting acoustic requirements.

6.4.5 Regulation

The high volume of fresh air required to meet the C2C criteria may conflict with the requirement for low energy consumption (heating, cooling, power consumption of fans) and the general requirement for space efficiency; to address this, the volume of fresh air should be controlled according to actual requirements (eg presence detectors, air quality measurements; window contacts).

It should also be kept in mind that it should be possible for users to influence room air quality (air flow rate as well as temperature).

To comply with the C2C criteria, the indoor air quality and the exhaust air quality must be measured during the operation of the building.

6.5 System sizing

As soon as the systems are selected, the usual system design specifications and the design criteria defined under “Design Criteria and Boundary Conditions” apply; it is likely that as a result, the systems will become significantly larger than in conventionally designed buildings.

The design may conflict with other C2C criteria (eg economy, space requirements; heating demand, power consumption of cooling and fans); here, priority is to be given to indoor air quality – other objectives are secondary, as long as the power and heat supply comes from renewable sources and the building materials used comply with the respective C2C material specifications.

Due to the large air flow rate required in C2C-inspired buildings, variable volume flow control makes sense – even if energy savings may not be required to meet the C2C criteria, space savings will be required in most cases..

Where a reduction in energy consumption is desired, passive measures (natural ventilation, climate-active materials (eg clay, greened surfaces etc.) should be prioritised.

The occupants’ thermal comfort could require humidification of the outside air, which will influence the size of the system and the design of other disciplines (water supply, heating, electrical supply).

When designing the ventilation systems, the pressure drop of the required filters – possibly also that of ‘biological filters’ – must also be considered.

To prevent the formation of microbes or mould, the WELL certification for air conditioning systems, for example, recommends a quarterly inspection or the use of a UV lamp to treat the cooling coils and the drain pan;¹²⁴ provisions for this should be considered in the tender documentation.

The position of the exhaust and fresh air intake grilles should be chosen to fulfil the C2C criteria, eg the flow of exhaust air through greenhouses (or at least where it has the least impact) or the intake of fresh air in green areas (or at least as far away as possible from polluted areas – eg on the roof and not at street level). Sources of free heating and cooling should also be considered for the intake and exhaust air locations, for example considering natural shading or natural heat sources.

Depending on the position of the outside air intake grille, insect filters may have to be provided; in any case, a particle filter should be installed after the exhaust air fan, to prevent abrasion from the fan from entering the environment.

At present, there are no design criteria available for the size of plant areas or greenhouses for outdoor or exhaust air filtration. However, reference values from the area of carbon fertilization for greenhouses can be used, where the yields are increased by increasing the CO₂ concentration. As a rule of thumb, the following values can be assumed for the CO₂ fixation of plants:¹²⁵

- Vegetable cultivation: 150 to 200 kg CO₂/a
- Ornamental plant cultivation: 25 kg CO₂/a

It should be noted that the CO₂ concentration in greenhouses is limited to 5,000 ppm for health and safety reasons, but it is very unlikely that this value will be exceeded by building exhaust air.

The distribution systems are to be designed for low material consumption wherever possible (shortest possible paths, eg systems as close as possible to the supplied area); the application of the T-method (design of the air ducts in such a way the same pressure drop in all air paths is the same as in the critical path, thus achieving smaller duct sizes), for example, can be taken into consideration.

Whether an energy saving through larger air ducts (= lower pressure loss) is sensible from a C2C point of view will depend on whether the fans are driven with renewable energy (in this case it would only be a question of economy) and the material of the air ducts and insulation (if they are made of materials suitable for C2C, there would be no material limitation).

When designing the distribution systems, it is important to ensure accessibility for cleaning (inspection openings) and filter replacement, as well as ease of commissioning.

Thermal comfort also includes draught-free ventilation; this is already considered in detail in existing literature, so that it will not be covered in this document.

6.6 Material selection

As far as the materials of the central and terminal equipment are concerned, there is currently little possibility of insisting on C2C-inspired materials, manufacturing processes or aptness for disassembly due to the market situation; however, it would help the market expansion of the concept to request information from the manufacturers in each case.

It would probably also help if MEP designers cooperated with manufacturers to review and pilot (even if only in a part of the installation) C2C-inspired products – this could lead to a rethinking and the development of new products, materials, or construction methods.

6.6.1 Air-handling units

An air-handling unit consists of a number of various components. It is not possible to deal with all of them individually within the scope of this guideline – this might be a topic for further work – but the most important plants are evaluated below.

At the time of writing, there was no *Cradle to Cradle Certified™* air-handling unit or only *Cradle to Cradle Certified™* components. However, air-handling units are usually composed of individual components that come from different providers, so that they can also be dismantled again for possible further use.

The body of the air handling unit (AHU) is usually made of metal, which is easy to recycle; more critical is the lacquering – which should be avoided as far as possible in C2C-inspired buildings. If the intended use does not allow it otherwise, acrylic varnishes are preferred to synthetic resin varnishes (further information in chapter [5.6.4 "Space heating equipment"](#)).

Thermal insulation of the body of the AHU would be another area in which C2C criteria apply; the various materials are already covered in chapters [3 "Water systems"](#) and [5 "Heating systems"](#). The choice of material is to be clarified with the manufacturer and, if necessary, specified for C2C conformity.

6.6.2 Fans

In general, C2C does not specify a specific type of fans; decisive for fan selection according to C2C criteria are materiality, energy use, and design for disassembly.

For the former two, direct drive fans have advantages over indirect drive fans (with pulleys), as less material waste is generated (no need to replace pulleys) and air quality is potentially improved (no pulley material is carried downstream).

The rotor blades are usually made of stainless steel, aluminium or GRP. Due to their poor recyclability, GRP blades should be avoided. Composite or mixed materials (eg aluminium and GRP) are also not to be preferred due to their poor recyclability – unpainted stainless steel would be preferred from a C2C point of view.

The C2C criteria for construction (design for disassembly) must also be followed; this is usually the case for larger fans, but could be a selection criterion for smaller fans and should be requested from the manufacturer.

At the time of writing, there are no *Cradle to Cradle Certified*TM or other fans of similar quality.

6.6.3 Heating and cooling coils

Heating and cooling coils are already dealt with in chapter [5.6.4 "Space heating equipment"](#).

6.6.4 Humidifiers

According to C2C, there are no special requirements for humidifiers other than the criteria for materiality, energy use and design. Whether a special humidifier technology is suitable for the health of the user must also be considered when selecting the technology according to C2C criteria.

In the context of the research for this guideline, no significant differences in health compatibility between the technologies could be identified; spray and ultrasonic evaporators, however, have a higher risk of germ development, so that steam generators would be preferable in this respect. The latter, however, are more difficult to operate with renewable energy, especially in the case of application (winter). Which technology is used must be planned for the respective project and the individual decision criteria must be weighed against each other.

At the time of writing, there are no *Cradle to Cradle Certified*TM or humidification systems with similar quality criteria.

6.6.5 Air washers

In principle, an air washer is a humidifier that also cleans the air; water is used as the filter medium, which is a positive factor considering C2C criteria. Because of the similarity with air humidifiers, a reference is made here to the notes in the corresponding heading.

Air washers are mainly based on spray or trickle humidification, so particular attention must be paid to hygiene (accessibility, provisions for disinfection).

At the time of writing, there are no *Cradle to Cradle Certified*TM air scrubbers or air scrubbers of the similar quality.

6.6.6 Filters

Filters are made of a material for the frame (plastic, cardboard or metal) and a filter material. Depending on the requirements and how many stages the filter has, pocket filters, HEPA cells, filter mats or activated carbon cartridges are used.

At the time of writing, there is no *Cradle to Cradle Certified*TM filter available on the market; however, since the filters are a consumer product, it would be good to ask manufacturers for *Cradle to Cradle Certified*TM products in order to encourage them to certify or follow C2C criteria.

There is no clear recommendation regarding the filter material; the criteria in chapter 13 "Material" generally applies. Care must be taken to ensure that the product is as ecological as possible, made of mono-material, and easily recyclable.

So far, there is hardly any information available on the recyclability of filters. Research carried out in preparation for this guide indicates that most filters are incinerated in waste incineration plants after their disposal (some companies even advertise the "incinerability" of their filters), which does not count as recycling according to C2C.

There are washable or regenerable filters which are preferable, but there is currently a lack of reliable information as to whether they can be recycled at the end of their useful life.

Glass fibre fleece could theoretically be recycled (eg OTTE Kunststofftechnik GmbH). In the case of filters made of synthetic fibres, the used materials must be examined more closely. There are already products made from recycled fibres, but the problem of disposal remains.^{126,127}

Depending on contamination, disposal at a hazardous waste landfill may also be necessary.¹²⁸

In addition to air scrubbers, activated carbon filters can also be used as filters for odours and gases. Activated carbon can be obtained from hard coal, coconut shells, wood, peat and similar materials. According to C2C criteria, the use of hard coal as a fossil raw material is not permitted; when extracting activated carbon from renewable raw materials, attention must still be paid to regionality – in Germany, activated carbon from wood (after several cascade usages) would be preferable to activated carbon from coconut shells.

Which material is used depends on the usage type and the material to be filtered. When selecting the filter, the highest possible reactivation capability (or already reactivated activated carbon) of the material should be selected.

¹²⁶ Freudenberg Filtration Technologies SE & Co. KG, n.d.

¹²⁷ Filtec Luftfilter, n.d.

¹²⁸ Wieninger GmbH, n.d.

For some applications (desulphurization of natural gas, separation of ammonia from the air) an impregnation of the activated carbon can increase the filter capacity; however, according to C2C criteria (restriction of recyclability) an impregnation is not desirable. The effects and origin of all possible impregnations could not be analysed in detail during the preparation of this guideline, but a coating of the activated carbon would have to be carried out with a substance optimised as far as possible according to C2C criteria; the impregnation should also not reduce the reactivation capability of the activated carbon.

Activated carbon filters are manufactured as plates, cells or cartridges. A refillable design must be ensured; cartridges are offered refillable.

Another possible filter technology would be electro-static filters. These filters are mainly constructed of different metal parts; the filter material can also be reactivated. More detailed research would still have to be carried out, done but in principle electro-static filters can meet the C2C criteria, as long as they do not contain inadequate materials and they are supplied with regenerative energy.

At the time of writing, there are no *Cradle to Cradle Certified*TM or filters with similar quality available on the market; a clear recommendation which filter technology best meets C2C criteria could not be given – it will depend on the individual case and filtration requirements.

6.6.7 Attenuators

The absorption material of the attenuator is usually mineral wool; the casing and the perforated inner lining are usually made of galvanised sheet steel, aluminium or plastic. Regarding steel, the same remarks apply as for ventilation ducts (see 6.6.8 "Ducts"). Aluminium is also easily recyclable, but requires a higher amount of energy, so steel would be preferable. Information on the employed plastics is currently not available from the manufacturers; for this reason, their use should be limited / avoided.

In general, a statement as to which material is better suited according to C2C criteria cannot be made definitively due to the limited information on all materials.

The recycling of rock/mineral wool is theoretically possible but requires special recycling logistics that still has to be set up. The company Rockwool takes back rock wool after the use phase and makes new rock wool from it ("Rock Cycle"), but so far this is limited to material from roofing products – for sound absorbers from mineral wool there is no recycling of this kind yet.

As an alternative to mineral wool, there are also silencers that use melamine resin plastics. Whether these fulfil the C2C criteria of material health or recyclability could not be clarified as part of the guide; a patent has been applied for a recycling process for melamine resins, but this shows that melamine resins are difficult to recycle¹²⁹, and no information could be found as to whether this process is already in use.

At the time of writing, there are no *Cradle to Cradle Certified*TM attenuators available.

6.6.8 Ducts

Rigid ducts for ventilation systems are usually made of galvanised sheet steel¹³⁰. This material can be used for a long time and a recycling cycle has already been established. For special hygiene requirements, pipes made of stainless steel sheet are also used, which can also be recycled.

The disadvantage is the energy-intensive recycling process for both materials, which until now has only used fossil energy; alternative materials should therefore be considered wherever possible.

The only *Cradle to Cradle Certified*TM ducts are currently made of textile fibre (Cradlesox and Cradlevent); both reach the Bronze level. The textile tubes are easy to clean; they are also taken back by the manufacturer and recycled for the technical cycle.

Image 14: Ducts made of cardboard, Gatorduct



Another alternative consists of cardboard ducts (Gatorduct); the system is designed for disassembly, and the manufacturer states that the entire product is 100% recyclable. The cardboard could well be suitable according to C2C criteria, but it comes with a special coating for fire protection; according to the manufacturer¹³¹, this coating is water based, chemically analysed, and is not harming the recyclability of the cardboard. Information is currently unavailable as to whether this will enable full recycling for all components; however, the manufacturer claims it is apt for a 40-year period of use (10-year warranty included).

The cardboard ducts can be cleaned in the same way as steel ductwork (eg negative compressed air method using a soft tipped brush). The coating is hydrophobic and ensures that no dust or dirt can settle and embed into the material wall.

Ducts made of aluminium-coated glass wool (eg Climaver from Saint-Gobain Isover) are a popular alternative to ducts made of steel sheets, particularly in the Mediterranean region. They are valued for their rapid installation, low price, and weight. A recycling of post-consumer glass wool (theoretically possible) is currently not in place; the

¹³⁰ Krimmling et al., 2014, p. 183

¹³¹ E-Mail correspondence, 27.09.18

coating of the glass wool with aluminium makes recycling even more difficult, so that according to C2C criteria, this type of ducts should not be used.

In particularly corrosive environments (eg swimming pools), plastic ducts are also used; this is considered a special case and is not evaluated here.

A clear statement as to which material is best suited for rigid ducts according to C2C criteria cannot be made in the context of this guideline; the cardboard ducts might be a case for a pilot.

In addition to rigid air ducts, flexible ducts are used for the connection to the air outlets; these usually consist of a steel spiral and an aluminium and/or plastic foil.

Flexible ducts should not be made of PVC, as it is included on the C2C PII's "Banned List"; flexible ducts consisting only of a steel spiral and aluminium foil (multi-layer) and connected by a seam connection are to be preferred.

At the time of writing, only the textile ventilation ducts mentioned above are *Cradle to Cradle Certified*TM. *Cradle to Cradle Certified*TM or C2C-inspired flexible aluminium or steel pipes are not yet available.

6.6.9 Thermal insulation

Different thermal insulation requirements (eg protection against mechanical stress, weather resistance) apply to different types and installation situations of ducts and different locations of air-handling units; this guide only deals with the suitability of the insulation materials for the use in C2C-buildings, not with their suitability for specific applications.

At the time of writing, there is only one thermal insulation (PE) for ventilation systems that fulfils the C2C criteria (Thermaflex "ThermaSmart Pro Sheet"; *Cradle to Cradle Certified*TM Bronze Level); at the time of writing, this material would be the only recommendable duct insulation material in C2C-inspired buildings (until other certified materials become available).

Rock wool (laminated with aluminium): The recycling of rock/mineral wool is theoretically possible, but requires special recycling logistics that still have to be set up. The company Rockwool takes back rock wool (until now only for roofing products) after the use phase and makes new rock wool out of it ("Rock Cycle"); however, for duct insulation there is still no recycling of this kind.

Aluminium lamination makes recycling even more difficult and should be avoided in C2C-inspired buildings wherever possible.

Rubber: Rubber insulation for ventilation systems is not permitted according to C2C criteria due to the VOC content and the frequently used flame retardants (chlorinated paraffins). Although Armacell has launched an "Eco-Cycle" programme to collect construction waste and recycle it with the aim of producing a product from 100% recycled material, the built-in rubber insulation is extremely difficult to recycle due to the use of glue for its installation.

PE: Thermaflex has a *Cradle to Cradle Certified™ Bronze* Level PE insulation called “ThermaSmart PRO sheets” for ventilation systems. There is still room for improvement, but the mono material is recyclable, and a material analysis has been carried out. The material still has to be glued, which compromises the recycling quality.

Adhesive: In addition to the insulating material itself, the frequently used adhesive connections must also be considered; in addition to the type of adhesive, the recyclability / separability of materials must not be reduced by the type of installation.

At the time of writing, there is no *Cradle to Cradle Certified™* adhesive.

6.6.10 Fire protection for ducts

Fire protection boards are usually manufactured on the basis of cement-bound calcium silicate (eg Promat, Knauf). Calcium silicate boards meet the criteria of the evaluation system for sustainable construction, but are a mixture of different mineral building materials and are glued or cemented over the entire surface, so that it is currently not possible to recycle them by type; so far there is also no system for reusing the products (eg Knauf products have a percentage of recycled material).

Due to the lack of recyclability (disposal at landfill¹³²), this product is not to be recommended according to C2C criteria (further information at www.wecobis.de); a detailed examination and investigations of recyclability may change this view in the future.

Image 15: C2C Certified™ calcium silicate boards from Evonik

There is a *Cradle to Cradle Certified™ Gold Level* insulation “Calsostat®” from Evonik; this has material properties similar to calcium silicate but is free of toxins and recyclable, according to manufacturer specifications.¹³³



In addition to calcium silicate boards, fire protection elements made of mineral wool (eg Isover Ultimate) are also used.

One advantage is the reduced use of adhesive due to the use of spring screws or wire joining techniques. According to the manufacturer, the material can be recycled, but only production waste is recycled for now; otherwise a disposal on a landfill, building waste or downcycling as bulk material is intended.¹³⁴

At present, no more suitable products are known, so that for compliance with the fire safety regulations, the use of the currently available materials is accepted; due to the lower use of C2C-unsuitable material, the use of fire dampers are in principle preferable, although this depends on the installation situation, ie the amount of material saved.

During construction, care must be taken to ensure that the material can be disassembled, and that the material purity is not reduced by mixing with plaster, impregnation or similar materials.

¹³² Promat GmbH, n.d.

¹³³ Evonik Resource Efficiency GmbH, 08.17

¹³⁴ Isover G+H, 2018

6.6.11 VAV boxes / volume flow controllers

VAV boxes consist of various components; it is not possible to deal with all of them individually within the scope of this guide – this might be a topic for further work. The main components are evaluated in the following paragraphs.

As far as the body of the controller / damper is concerned, the same applies as for air-handling units, with VAV boxes usually having no surface treatment (a question for the manufacturers when selecting the equipment).

The control elements are dealt with in chapter 12 "Building management / controls systems"; there is little possibility of influencing their suitability for C2C.

6.6.12 Fire dampers

As with VAV boxes, the bodies of fire dampers are usually made of metal (galvanised sheet steel or stainless steel), which usually does not have a surface coating.

The damper blade is made of calcium silicate (eg Trox¹³⁵) or metal. According to C2C, metal would be preferable as it has better recyclability; however, safety requirements must be observed.

A seal made of elastomeric plastic or sealing elements made of non-combustible mineral fibre with a layered glass fabric coating (eg Litaflex¹³⁶) is used on the damper blade. A general statement on the C2C suitability of such seals cannot be made due to a lack of manufacturer information; however, due to the use of adhesive and impregnation, C2C suitability is questionable.

At present, there are no better products known, so that their use in compliance with fire safety regulations must be accepted.

The control elements are dealt with in chapter 12 "Building management / controls systems"; there is little possibility of influencing their suitability for C2C. Whether electrical or pneumatic systems are used is irrelevant for C2C suitability.

135 Rüegg, 2002

136 Rex Industrie Produkte, n.d.

6.6.13 Supports and fixings

Duct supports and fixings are usually made of metal; although this is energy-intensive during production, it generally enables high-quality recycling, so that such systems can always be used in C2C-inspired buildings.

Adolf Würth GmbH offers a *Cradle to Cradle™ Silver Varifix®* rapid assembly system.

6.6.14 Grilles & diffusers

Grilles and diffusers are usually made of metal (steel, aluminium) or sometimes (lower quality) plastic. Metal air diffusers should be given priority in C2C-inspired buildings because of higher recyclability and durability.

A problem with grilles and diffusers is their surface treatment. In principle, untreated surfaces made of stainless materials would be preferable in C2C-inspired buildings, but they are not available in all cases – usually either paint or a powder coating with thermoplastics (PE, PA, PUR) are applied.

To be apt for the use in C2C-inspired buildings, these plastics must be designed according to C2C criteria and be recyclable by material type.

A distinction is made between synthetic resin and acrylic paints. Synthetic resin coatings contain a higher proportion of organic solvents and thus a higher VOC concentration than acrylic coatings¹³⁷. Acrylic lacquers are therefore preferable to synthetic resin lacquers, but they also contain organic solvents and should therefore be used as little as possible.

A statement as to whether paints or powder coatings are preferable from a C2C point of view could not be established during the preparation of the guideline; the general view of the involved materials experts is that both have advantages and disadvantages that would make one solution favourable over the other depending on the individual case – in some cases, the more durable powder coatings would be preferable to extend the expected lifetime of a product, in others the paints that can be removed more easily for recycling.

At the time of writing, there were no certified air diffusers; in the meantime, air diffusers made of stainless steel or galvanised sheet steel are best suited to meeting the C2C criteria, although anodised aluminium air diffusers could also be considered.

6.7 Construction methods

The connections in ventilation systems must be as separable as possible (clamping, screwing, etc.). Bonding or filling leaks with plastics must be avoided; thermal insulation must also not be glued.

All ventilation systems must be as accessible and apt for dismantling as possible; a modular design is preferable, to allow replacement of modules rather than the complete plant.

7. Cooling systems

7.1 Aims and evaluation criteria

7.1.1 Overview

C2C aim	There are no 'own' aims for cooling systems - they only support the C2C aims of other systems (eg an indoor climate that promotes wellbeing)
C2C minimum criterion	Optimisation of cooling loads and material consumption
C2C no-go criterion	Supplied with electricity from fossil fuels; use of materials on the "banned list of the C2CPII"
C2C material criteria	See chapter 13
C2C construction methods	See chapter 14

7.1.2 Explanation

The only C2C criterion that cooling systems directly influences is a healthy indoor climate; they also have an influence on energy consumption, air quality and materials, but these are not specific to cooling, so no unique criteria were established for these systems.

When they are considered in a C2C context, cooling systems should be considered as products whose materiality should be optimised; their design should aim to optimise their contribution to the indoor climate (limitation of maximum temperatures and humidity), their effect on air quality, microclimate and their energy use; this could include a critical consideration of the necessity of systems or elements - fewer elements and fewer systems require less material and energy and pollute the air quality less.

In the guideline, all disciplines are considered individually and individual aims are formulated. However, the electrical installations, heating installations and cooling installations can pursue the aim of positive energy self-sufficiency as an integrated, overall system. The boundary for the energy balance should be set over the entire MEP installation and an overall energy concept should be drawn up, which does not only consider individual disciplines.

As a result, the design for cooling systems should be evaluated in its overall context, ie whether the systems weaken or support the C2C objectives of other groups of installations. As an example, conventional refrigeration systems consume a lot of electricity; alternative systems such as adiabatic cooling consume a lot of water, which is polluted in the process, and usually requires more space. In both cases it would help to optimise the cooling demand, which would also reduce material consumption - which is also influenced by the choice of system.

The same applies to a healthy indoor climate; apart from cooling systems, it is significantly influenced by ventilation systems, heating systems, architecture, façade design and interior design, so that an overall concept must be found to achieve a healthy indoor climate.

7.2 Design criteria & boundary conditions

During the establishment of the brief, the no-go and minimum criteria should be listed; it should also be defined how the cooling systems contribute to a healthy indoor climate, ie to which temperatures or maximum humidity cooling is to be provided in which zones.

It is difficult to define a generally valid criterion for optimising the energy consumption of only the refrigeration systems, as this depends strongly on the respective use and the climatic conditions; the total energy consumption of the building is also relevant, and here there are large interdependencies between the systems. Material consumption depends almost directly on the energy consumption and is also optimised by optimising the energy consumption.

As a first step, it should be critically questioned whether all systems are necessary, and the aim of an effective use of materials and energy should be set; aims from sustainability certification systems could be used for energy consumption. (eg DGNB rewards an over-compliance with the German energy regulations of at least 30% (platinum criterion)¹³⁸, and LEED has a similar approach).

The desired economics in the implementation of the C2C objective may result in further design values, eg efficiency levels of refrigeration, optimisation of space consumption, etc.; they should also be stated.

7.3 System selection

There are currently no *Cradle to Cradle Certified*TM refrigeration plants or cooling systems; the choice of systems should be based on the most effective use of materials and energy possible (as few elements as possible, consumption as low as possible, systems adapted to renewable energy production) and, where possible, on the ability to create a healthy indoor climate.

7.3.1 Optimisation of cooling consumption

In most cases the optimisation of the cooling consumption will not depend directly on the designer of the plant but on the designers of other disciplines; for example, an efficient shading would depend on the object planning, an energy-efficient lighting on the electrical designer, etc. The cooperation of all disciplines should be sought, where the designer of the cooling system should indicate how the refrigeration consumption could be reduced and the recyclability can be increased.

Optimised building design: The building design should be optimised in terms of heating and cooling technology. This includes for example percentage of glazing, solar protection, thermal mass, or free cooling. As these measures are already discussed as a standard or in various publications, they are not addressed in this guide.

Biological cooling: Plants in the exterior and interior of the building contribute to the cooling of the building and the city, whether in the exterior through shading, thermal inertia, or water evaporation, or in the interior (also through evaporation).

At a building level, new research by Arup shows that for most typical office buildings the mean and peak energy demand for cooling can be reduced by 2...8% per year by green facades¹³⁹; the energy saving depends on the height to width ratio of the building façade. Apart from the cooling effect for the building, a green façade also has beneficial effects on the acoustics of the building, well-being of the inhabitants, biodiversity and against heat islands in cities. Green facades are therefore generally worth supporting also according to C2C criteria.

It is difficult to estimate the cooling capacity of the various individual plants; in a literature research only isolated values were found which are difficult to compare with the cooling capacity of an air conditioning system. In this area, more knowledge needs to be generated and it needs to be recognised that plants can have a large proportion of positive effects on buildings, which provides a synergy effect in meeting the C2C objectives.

Energy efficient systems: MEP systems generate heat in use, which must then be dissipated by the cooling systems. All systems should be optimised in this respect, eg by low-energy lighting or demand-based lighting, energy-saving lifts, etc.

Ventilation plays a special role here; it has a particular influence on cooling consumption. An optimisation of the fresh air supply (eg demand-based ventilation) and efficient heat recovery would be regarded as minimum requirements here.

Building automation will also play a major role in energy consumption; the control of solar shading and the systems mentioned above will contribute to optimising consumption.

7.3.2 Refrigeration system

When selecting a cooling system, it is important not only to optimise the energy consumption but also to consider its suitability for operation with renewable energy, eg the use of solar thermal energy; this operation should then be as efficient as possible.

In addition to energy consumption, the cooling systems must be evaluated in the same way as conventional products – the C2C criteria for materiality and design must be followed. However, at the time the guideline was drawn up, there were no chillers made of C2C-inspired materials or manufactured with equivalent quality.

The C2C principle does not specify whether the systems are to be designed centrally or de-centrally, or as air-cooled, air/water or water-cooled systems.

Compression chillers: When selecting a refrigeration system, not only the energy consumption but also the noise level (influence on the healthy indoor climate) can play a role in the C2C evaluation.

The standard solution for cooling generation on the market consists of compression chillers, which are usually selected according to performance, price and, if applicable, noise emission. According to C2C criteria, there is no clearly favoured system here – the choice of system depends on the application.

When choosing between water-cooled or air-cooled systems, there is also no clear preferred choice according to C2C criteria. Water-cooled systems (with separate heat rejection) are characterised by higher energy efficiency, but have a higher material consumption, a higher space requirement and are usually more expensive overall.

A challenge when choosing a system according to C2C criteria for all chillers is the refrigerant; this topic is considered in more detail in the section [7.5 “Material selection”](#) and should be taken into account in the design.

Absorption chillers: The use of absorption chillers, where the refrigeration process is driven by heat, is often considered in terms of the use of ‘waste heat’.

From a C2C point of view, the use of such a technology only makes sense if this heat is available either from a solar source or as a by-product of another process (without re-heating); due to the strong dependence of efficiency and material consumption on the temperature of the heat transfer medium, only steam above 115°C can be considered for the latter, and for solar supply only vacuum or high-performance collectors.

The significantly higher space (and energy) requirements for the heat rejection should also be taken into consideration (the heat used for the operation must be removed in addition to the excess heat of the building); from the C2C point of view, the technology only makes sense if the heat can be removed to a seasonal heat storage unit, since the material consumption is about three times higher with air cooling than with compression cooling. However, an evaluation of the overall energy consumption might make the system interesting again, ie to achieve the aims for regenerative electrical energy coverage.

See chapter [7.5.2 “Refrigerants”](#) (lithium bromide).

7.3.3 Heat rejection

For heat rejection, a distinction is made according to the medium to which the heat is rejected (air-cooled, water-cooled (= groundwater, lake/river water, seawater), ground source); C2C criteria are affected by all systems (air quality, energy use, water consumption, material use), so that no system is favoured from a C2C point of view – the systems would have to be evaluated in the overall context.

Dry cooling: In dry cooling, the cooling medium is cooled exclusively by convection driven by the temperature difference with the outside air. The heat transfer is limited, so that the space and material requirements of such systems are relatively large; moreover, the process only functions at relatively high temperatures of the cooling medium, which makes the cooling process less efficient.

In this sense, this type of cooling is less suitable for C2C-inspired buildings (although its use is not an exclusion criterion), particularly in view of the difficulties in ensuring the use of C2C-inspired materials in refrigeration systems.

Wet cooling: In wet cooling, water evaporates in the air used for cooling the cooling medium, reducing the air temperature and using the evaporative cooling for refrigeration.

While this saves energy and material, it conflicts with the aim of reducing water consumption. Where reused water is used, this conflict does not exist; where no reused water is used, an evaluation of the system overall (also: energy consumption, space consumption) must be carried out to reach a decision on the system.

Free cooling: A special case of cooling generation is water-side free cooling, where the refrigeration plant is switched off at lower outside temperatures and the cooling medium is only cooled by the air-side heat exchanger (ie bypassing the compression process); even if a higher material consumption is required here, such a passive solution in the sense of an optimisation of energy consumption is to be supported from a C2C point of view (but it should be considered that an efficient use of such a system requires a suitable room-side cooling system, which operates at the highest possible flow temperatures).

Adiabatic cooling: A special case of wet cooling is the so-called adiabatic cooling, in which water is sprayed into the air flow of the ventilation system and the evaporative cooling is used to cool the supply air; here a distinction is made between direct cooling (injection into the supply air) and indirect cooling (injection into the exhaust air, recovery by heat exchanger).

Image 16: The extension of the Bavarian Parliament is using adiabatic cooling in its air conditioning system



In principle, the system is suitable for C2C use, as it reduces energy consumption. However, it should be kept in mind that the system increases water consumption and the water may need to be treated so that it may conflict with the objectives of water use; from a C2C point of view, therefore, such a system would only make sense if reused water was used for spray cooling (for which indirect cooling would be more appropriate).

Split units: In split units, the cooling circuit is divided into compressor and evaporator, with the compressor being installed as an external unit and the evaporator in the room unit being used as the cooling element; the cooling medium is the cooling fluid in the cooling circuit.

Split units initially have a lower material consumption because the refrigerant is distributed at lower temperatures, and no internal heat exchangers are required; at the same time, the lower system temperatures do not allow the use of alternative energies or an overall system optimisation for energy consumption, and the increased use of refrigerant leads to a higher risk of air pollution, so that split units – although not directly excluded – are not favoured for C2C-inspired buildings.

7.3.4 Solar cooling

Solar cooling is a process in which refrigeration is generated by solar energy. A differentiation has to be made between three systems¹⁴⁰: The use of electricity generated by photovoltaics, solar thermal systems (sorption-supported refrigeration (SGK or DEC), absorption refrigeration process, adsorption refrigeration process, steam jet refrigeration process) and thermomechanical systems (Vuilleumier and Rankine processes).

Photovoltaic: The use of electricity generated by photovoltaics is dealt with in the chapter 8.4.1 “Electricity generation”.

Thermomechanical: Thermomechanical systems are currently not commercially used in buildings and are therefore not considered further in this guide

Solar thermal: The solar thermal systems can be divided into closed and open systems.

The technologies of the closed systems (desorption and adsorption chillers) are presented and evaluated under “Absorption chillers”. Open systems are in principle described under “Adiabatic cooling”, where solar energy is used to re-charge (= dry) the sorption agent.

In open systems, a further distinction exists between solid and liquid sorption. In the case of solid sorption, rotary dehumidifiers with a sorption agent are used, whereas in the case of liquid sorption substances such as lithium chloride are sprayed liquid into the refrigerant (eg water) as sorption agent. The lithium chloride is then removed from the refrigerant and kept in a continuous circuit.

It is not yet possible to make a final statement about these two systems, as information about the materiality – and thus compliance with the corresponding C2C criteria – of these systems is not known. The respective application, the energy consumption, and the possible coverage with renewable energy will also play a major role in evaluating the feasibility of such a system; as an example, liquid sorption enables air conditioning systems to be operated outside the operating hours of the solar collectors at the Energy Efficiency Center project in Würzburg, and thus helps meeting the energy criteria.

At the time of writing, there are no complete systems with *Cradle to Cradle Certified*TM components or of similar quality. In addition to the sorbent, all other components must of course also be optimised according to C2C criteria; see also the comments under [13 “Material”](#).

7.3.5 Energy storage

Storing the cooled media can significantly reduce energy consumption in refrigeration, but lead to higher material consumption, and therefore to a contradiction between two C2C aims.

As long as C2C compliant materials are used in the construction of the storage, material consumption is not as relevant; as long as regenerative energy is used for refrigeration, energy consumption is also irrelevant. If both criteria are met, space requirements or economy may determine the decision.

Latent heat storage: Because of the higher efficiency of cooling at night (lower temperatures; “off-peak” in electrical energy generation), heat storage systems are particularly interesting for refrigeration systems; moreover, most refrigeration technologies require a buffer storage tank anyway, so no additional system is required (only a larger one).

Latent heat storage systems are dealt with in more detail in [chapter 5 “Heating systems”](#).

Seasonal heat storage: Due to the relatively high energy consumption (even more so when primary energy is considered), seasonal heat storage for refrigeration – which occurs as a “waste product” when heat pumps are used, for example, or can be stored freely in winter – is particularly interesting in terms of energy-efficient refrigeration. Seasonal heat storage units are also described in more detail in chapter 5 “[Heating systems](#)”.

7.3.6 Cooling distribution

The distribution of cooling differs only insignificantly from the distribution of heat; see explanations in chapter 5 “[Heating systems](#)”.

7.3.7 Room systems

The room systems should be selected so that they support regenerative refrigeration (ie that operating at higher flow temperatures); they should also enable a healthy indoor climate.

Where central ventilation is already available, it should first be checked whether it is sufficient for cooling; this would reduce the use of materials.

If room cooling is necessary, material use must also be considered here; from a C2C point of view, chilled ceilings would be preferable here, as they have the lowest material consumption.

However, activated thermal mass systems do not comply with C2C criteria; the casting-in of pipes in concrete – regardless of which material – leads to a connection that can no longer be dissolved, so these materials become waste and lose their value. The same applies to underfloor or ceiling heating systems that are also used for cooling; only systems that are constructed in dry construction and not cast in may be used (for more information, see chapter 5 “[Heating systems](#)”).

If chilled ceilings or chilled beams are not sufficient for the cooling load, active systems such as active chilled beams can be used; like chilled ceilings they use chilled water with higher flow temperatures, which also benefits the use of regenerative energies or free cooling.

Fan-coils are usually designed for lower chilled water temperatures and are therefore less suitable for C2C-inspired buildings; however, it is possible to design them for higher chilled water temperatures – although this increases material use. An exception to this is a new generation of fan-coils with low energy and material consumption (see Artus Hybrid Fan Coil¹⁴¹) which could be considered as an alternative to active chilled beams.

For a healthy indoor climate, systems with higher chilled water temperatures are preferable, as the temperature difference between supply air and indoor air makes a noticeable contribution to comfort; in this context, split systems – which operate at very low temperatures – should be avoided. At the same time, split systems require less material than conventional systems; however, as long as conventional systems are built with C2C compliant materials, the greater use of material is not relevant.

Which technology is most appropriate has to be decided individually for each project. The priority for C2C-inspired buildings is a healthy indoor climate; in terms of this priority, conventional systems are preferable to split systems. However, with proper planning of air flows and indoor climate, the advantage of split systems in terms of material use can be advantageous. It should be kept in mind that the elements of both systems have not yet been evaluated or optimised for C2C criteria by the manufacturers.

7.4 System sizing

As soon as the systems have been selected, the usual specifications of the system dimensioning, as well as the design criteria defined under “Design Criteria and Boundary Conditions” apply; in this context, efficient operation should be emphasised, eg efficient control of the systems and pumps and the interaction between the refrigeration system and the room system (system temperatures).

When designing the systems, attention should be paid to the reduction of energy consumption; the system should be designed for supplying the minimal demand, to avoid unnecessary material consumption by unnecessarily large central plants or networks. This also increases the technical feasibility of a 100% renewable electric energy coverage.

However, in this process the full lifecycle of the equipment should be considered; if it is likely that the cooling demand changes during the lifecycle of the equipment, the possible range throughout the lifecycle should be considered, to avoid having to replace equipment before the end of its lifecycle.

In larger projects with room systems and central systems with different flow temperatures, it is often necessary to clarify whether a single central plant with a lower flow temperature and a mixing valve or two plants, each operating at one of the flow temperatures (lower energy consumption, but higher material consumption), makes more sense. From a C2C point of view, if the chiller was completely supplied with regenerative energy, material consumption would have to be minimised (= one unit with mixing valve to be used), since there is hardly any influence on the materiality of the chillers.

The choice of refrigerant can play a role in the design of refrigeration systems; see the explanations in the chapter 7.5 “Material selection”. When using thermally-driven systems, it should be noted that the heat rejection capacity is approx. 3 times higher than with conventional refrigeration systems, which has a noticeable effect on the space required (external areas).

The costs for so-called “solar cooling kits” (collector, refrigeration system, periphery; without installation and cooling distribution) are currently 4,500 €/kW (systems between 8 and 15 kW) and 2,000...2,500 €/kW (systems with approx. 100 kW)¹⁴², and therefore significantly higher than the costs of conventional systems; however, the systems can also cover the heat requirement, which would have to be considered in an economic analysis.

Due to the risk of affecting air quality, cooling systems containing substances that could potentially pollute the air in or around the building should be equipped with a leak detection system; this will have an impact on costs and commercial viability.

For all systems it is important to ensure in the design process that the systems can be repaired and dismantled.

During the system design it would be helpful to confront manufacturers with the C2C issue (certification of elements and materials, list of materials used, dismantlability) and to favour manufacturers who are making efforts in this area.

7.5 Material selection

The C2C criteria for materials must be met (see chapter 13 “Material”).

When selecting materials, pressure should be applied on manufacturers and priority given to materials for which at least efforts have been made towards *Cradle to Cradle Certified*TM or C2C-inspired material.

7.5.1 Refrigeration & heat rejection systems

Due to the market situation, there is currently little possibility of insisting on *Cradle to Cradle Certified*TM or similar materials, manufacturing processes or dismantlability in the case of the materials used for the devices; however, it would help the market expansion of the concept to enquire of the manufacturers in each case – this could be the basis for a re-thinking process.

At the time of writing, there are no refrigeration or heat rejection plants that have been *Cradle to Cradle Certified*TM or built according to C2C criteria.

7.5.2 Refrigerants

At the time of writing, there is no *Cradle to Cradle Certified*TM refrigerant available.

As there is no refrigerant suitable for all applications, it is not possible to make a clear statement on the most suitable refrigerant when drawing up this guide.

Although the refrigerants available on the market for building systems are no longer hazardous to the ozone layer, most of them are still greenhouse gases that can be released if leaks occur. Even if no clear preference can be defined, single-component refrigerants would be preferable to mixtures (R4xx, R5xx), as the latter have to be completely replaced in case of leakages, while single-component refrigerants only have to be topped up.

It is expected that in the future - in response to changes in standards – systems with less climate-impacting refrigerants such as carbon dioxide (R-744), ammonia, propane or 2,3,3,3-tetrafluoropropene will come onto the market, which should then be used for C2C-inspired buildings.

The ammonia-water solutions used in industrial absorption refrigeration systems are not C2C-compliant due to water contamination; the lithium bromide water solutions commonly used in buildings are a hazardous substance, but are not on the C2CPII’s “banned list”; however, no recycling system is known for lithium bromide, so their use is questionable.

In solid sorption, silica gel or lithium chloride are used as sorbents. In liquid sorption, lithium chloride, for example, is used as the sorbent. With Aerogel, Cabot offers a silica gel that is *Cradle to Cradle Certified*TM (Silver level) - but only certified for building insulation; whether it can also be used as a sorbent was not confirmed by the manufacturer upon request.

Whether lithium chloride can fulfil C2C criteria as a sorption agent will have to be clarified in future work; at least it is not on the “Banned List” of the C2CPII.

Currently, there is no refrigerant available that is optimised for the biosphere; as a result, refrigerants have to be recycled in the technosphere. A recycling system for refrigerants is already in operation and regulated; this can lead to processing to the same quality or material recycling of the chemical ingredients in other applications¹⁴³ (see also chapter 5 “Heating systems”).

Nevertheless, refrigerants remain hazardous substances that must not be released into the environment; appropriate measures must be taken (see chapter 7.4 “System sizing”).

7.5.3 Pipes

Pipes for refrigeration systems are essentially the same as those for heating systems; they are therefore dealt with in subsection 5.6.3 “Heat distribution”.

7.5.4 Fastenings

Fixings for refrigeration systems are basically the same as those for heating systems; they are therefore dealt with in subsection 5.6 “Material selection” of the “Heating systems” chapter.

7.5.5 Insulation

Pipe insulation for refrigeration systems is essentially the same as that of heating systems; it is therefore dealt with in subsection 5.6 “Material selection” of the “Heating systems” chapter.

7.5.6 Accessories

Accessories for refrigeration systems are essentially the same as that of water or heating systems; they are therefore dealt with in subsection 3.6.12 “Accessories” of the “Water systems” chapter.

7.5.7 Room-side systems

The elements of the room-side systems are normally made of metal (steel, aluminium), and therefore their materiality makes them suitable in principle for use in C2C-inspired buildings; the visible parts are usually painted, which reduces the recycling quality.

In their construction, the elements of the room systems are similar to those of the ventilation and heating systems; please refer to the corresponding evaluation in the respective chapters.

At the time of writing, there are no room systems that have been certified or created according to C2C criteria.

7.6 Construction methods

Due to the substantial similarities in the construction methods of cooling and heating systems, reference is made at this point to the chapter “Heating systems” in the section 5.7 “Construction methods”.

8. Electrical installations

8.1 Aims and evaluation criteria

8.1.1 Overview

C2C aim	Positive electrical energy balance
C2C minimum criteria	Own renewable electricity production
C2C no-go criteria	Electric energy from fossil sources
C2C material criteria	See chapter 13
C2C construction methods	See chapter 14

8.1.2 Explanation

A positive electrical energy balance means that the building – including all devices connected to it (even non-permanently) – is supplied with electricity from renewable sources throughout the year, and that an excess of electricity is generated beyond that demand.

It is permissible to use regenerative electricity generated off-site, but part of the regenerative electricity must be generated on site; this share is to be maximised within the boundary conditions of the building and the site.

Regeneratively generated electricity can come from:

- Solar energy (eg photovoltaics)
- Wind power
- Hydropower
- Geothermal energy (special case)

Electricity from biomass is considered regenerative only in exceptional cases – see the comments (also on fossil fuels) in chapter 4 “Gases and fuels”.

Initially, it is not a C2C aim of its own to minimise electricity consumption; however, in the interests of the C2C aims, the economy of the building and the materials used to generate the electricity, a minimisation should be achieved. Energy efficiency is therefore a means to increase the share of renewable energy.¹⁴⁴

Figure 13 gives an overview on the components used in electrical systems, together with all inputs and outputs.

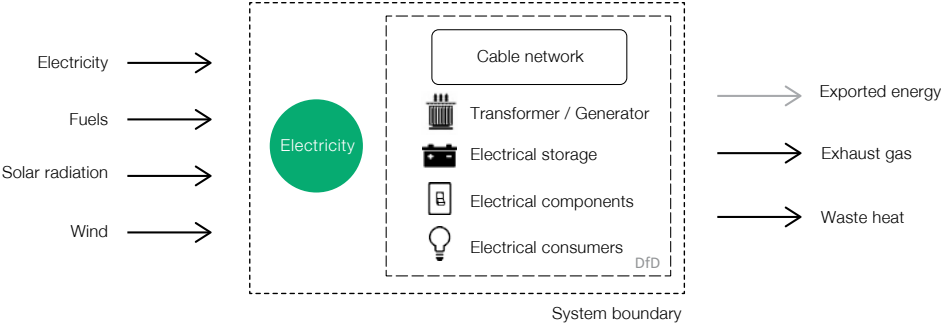


Figure 13: Overview electrical systems

8.2 Means of implementation

Achieving a positive electrical energy balance will usually involve employing solar energy; apart from energy storage, this will also require a reduction in consumption, to make the system economically viable and allow covering the demand with the space available for photovoltaic panels (or other renewable technologies) on site.

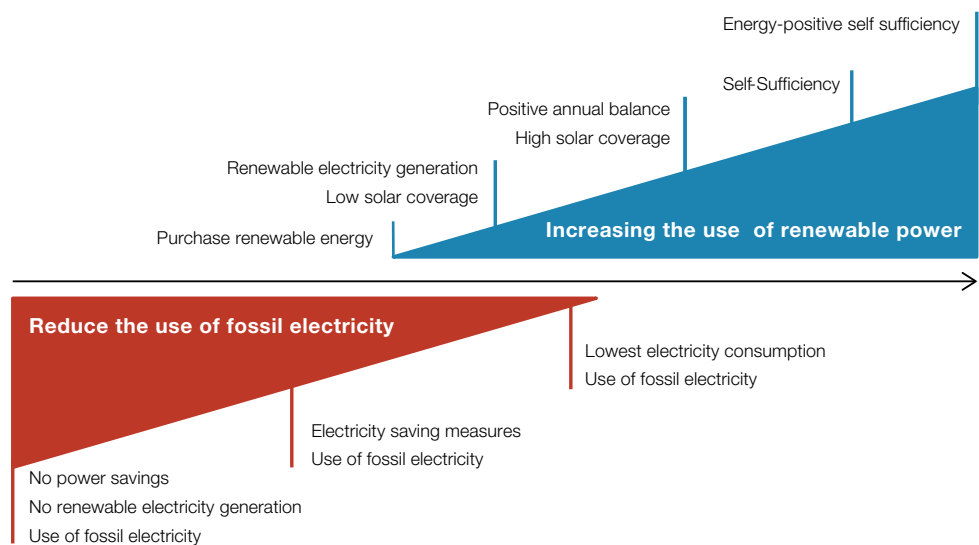
Reduction in demand can be achieved by passive and active measures; priority should be given to passive measures, and only the remainder should be reduced by active measures. A good part of the active measures will have to be employed in other disciplines, so the design should be coordinated carefully with the other design parties.

While own renewable electricity generation typically involves solar energy technology (other renewable technologies are difficult to integrate while remaining efficient), it is also possible to employ fuel cells or CHP plants that are powered by non-fossil fuels produced on site, or to use heat pumps that are powered by electricity from on-site renewables.

Means of avoiding fossil fuels are covered in the “Gases and fuels” chapter.

Figure 14 provides an overview and classification of various applications on a roadmap for electrical systems in C2C-inspired buildings.

Figure 14: Roadmap for electrical systems in C2C-inspired buildings



8.3 Design criteria & boundary conditions

During the establishment of the brief, it is to be defined which degree of coverage of regenerative electricity is targeted, and how much of it is to be generated on-site. Conflicts of objectives with other C2C objectives, and the technical necessity of technologies for which there are no C2C alternatives (eg industrial melting processes that cannot yet be carried out regeneratively), economy or space requirements have an influence on this definition. The aim should be to achieve the highest possible degree of solar coverage; the chapter 8.5 “[System sizing](#)” provides information on which levels of coverage can be realistic for buildings.

Where applicable, design criteria should be defined for the respective regenerative power generation, eg operating voltages or grid selection.

A boundary condition is the use or storage of the surplus electricity; here it may be necessary to define which conditions apply to feeding into the grid (eg type of metering). If electricity generated outside the building is used, the conditions for supplying this energy to the building must also be defined.

Other C2C criteria (eg the requirement for an inspiring and safe working environment, materiality, construction and maintainability) may result in further design criteria (eg shading system, lighting control, circadian rhythm); it is assumed that these are covered sufficiently by existing guidelines on these items.

The economics of implementing the C2C objective can also lead to further design data, eg lighting levels, losses in equipment and distribution, etc.

8.4 System selection

During the system selection, it must be established how the desired coverage of renewable electricity production is to be achieved – how is the electricity generated regeneratively, how is it stored?

It should be kept in mind that a 100% regenerative power supply simplifies the system selection and design of other systems (eg refrigeration) in the sense of C2C; this should be taken into account in economic considerations for the corresponding systems.

In the following sections, possible systems are evaluated regarding their C2C suitability.

8.4.1 Electricity generation

Photovoltaics: The integration of photovoltaic modules into the building envelope is already relatively well-developed, so that it will not be discussed further here; photovoltaics is in principle suitable for C2C. However, it should be noted that

- the use of own electricity for buildings with grid connection is still not yet economical in most cases, and
- due to the limited efficiency of the modules, the energy density of buildings, and the area-to-volume ratio of buildings, photovoltaic modules alone will in most cases not be able to cover 100% of the electricity demand with most traditional mounting techniques.

A power supply exclusively from non-fossil energy sources will therefore require a mix of technologies in most buildings.

When selecting the appropriate technology, C2C criteria for material selection may also become relevant; most photovoltaic cells are potentially manufactured with high environmental impact, and there are currently only two companies that are manufacturing *Cradle to Cradle Certified*TM PV modules (Jinko Solar and Sunpower; both Silver Level).

The recyclability of PV modules needs to be further improved, but at the moment they are replacing fossil fuels and supporting the transformation of energy generation, so their use in C2C-inspired buildings is recommended.

The use of PV can compete with other C2C aims (eg daylight, greening) for space on the building envelope; while it is possible to maximize daylight and effective PV concepts by using different angles and brackets to combine these two topics, and there are solutions to gain daylight and gain energy from PV at the same time (eg Energy Academy Building, Groningen, NL), a holistic view of the respective benefits and focus of the project is needed to find a suitable balance.

It should be kept in mind that the solar power generated by the building should initially be used for the building's own consumption, and only the surplus that cannot be stored should be fed into the grid.

Fuel cells: The integration of a fuel cell for buildings has only gained importance in recent years.

The fuel cells currently available on the market are powered by natural gas; in the process, hydrogen is reformed from natural gas and fed into the fuel cell. Technically it would also be possible to use hydrogen, liquid gas or methanol, but currently this is not offered. The technologies currently used (SOFC and PEMFC) are not discussed further in this guide, as they are not relevant for the suitability for C2C.

Which gas is used is critical for meeting C2C criteria; further information on this topic can be found in the chapter 4 “Gases and fuels”.

The fuel cell generates electricity and heat at the same time; this works well where there is a heating demand, ie in winter¹⁴⁵ or for the preparation of domestic hot water. However, when there is no use for the heat, electricity production makes little sense, which initially does not allow 100% coverage of the annual electrical demand due to the different usage profiles.

It is possible to use excess PV electricity to produce hydrogen in summer by electrolysis and store it for the winter; the special safety requirements for hydrogen storage must be taken into account here.¹⁴⁶ The use of locally produced biogas (eg from food leftovers) is also conceivable, although this possibility would still have to be examined on the basis of the economic efficiency and the possible amount of biogas to be produced. Both options would facilitate a 100% renewable supply, making solar power available for electrical supply and heating in winter.

Due to the short testing period of the technology, the economic advantage is still to be examined, and at present probably still difficult to assess.

In general, according to C2C principles, a direct conversion of solar energy into heat or electricity is preferable to a hydrogen-related conversion, since C2C-compatible production and distribution of hydrogen is currently still difficult and requires additional material.

Generator: In principle, a building can be completely supplied with its own generators; this is quite common in areas with limited or poor electricity grids, but in most cases not economical in areas with a grid connection.

The technology is relatively mature, so that it will not be discussed further here; topics are space requirements (also for the storage of the fuel), noise development, the design of the structure (loads, vibrations), as well as the exhaust gases.

However, due to the high material input and the lack of C2C compliant products, generators are not considered a promising solution for a renewable electricity supply; for C2C-inspired buildings it should even be examined whether an emergency power generator can be avoided by suitable measures (eg sprinkler circuit of the power supply, battery buffer).

Where generators have to be used, the fuels that power them have to meet C2C criteria; more detailed information on this in chapter 4 “Gases and fuels”.

145 Chartenko, 1997, p. 252

146 Nationale Organisation Wasserstoff- und Brennstoffzellentechnologie, n.d.

Wind turbines: While wind turbines are economically viable in windy areas outside built-up areas, their use on buildings is usually uneconomical.¹⁴⁷

Image 17: Wind farm for an industrial park (Cork Lower Harbour)



In principle, the larger the plant and the higher the average wind speed, the more economical the plant. The surroundings of buildings usually do not permit the construction of larger systems (shadowing, noise, approval capability); smaller systems in the range of less than 10 kW are usually only economical for applications without their own electricity infrastructure.

Buildings significantly reduce the average wind speed, so that no sufficient wind harvest is not to be expected in the surroundings of buildings to reach economic viability; in addition, local wind profiles and eddies form around buildings, which can even prevent the wind turbines from starting in the first place.

Wind turbines can make sense for large scale projects outside urban areas, eg one of Arup's projects in Cork (Ireland) used wind turbines to supply electricity to industrial parks¹⁴⁸, and others used on the outskirts of car parks in out-of-town shopping centres.

Hydropower plants: Hydropower plants will only be usable for buildings in very few cases, as they depend on a natural water source with a sufficient gradient, or industrial plants with a sufficient amount of water usage. As a special case, hydropower plants are not dealt with further in this guide.

Geothermal energy: The use of geothermal energy for electricity generation is rather a special case and cannot be used in most buildings; therefore, this guide does not deal further with this technology.

Green electricity from the grid: “Green electricity” from the grid has to be generated using one or more of the above technologies to be suitable for a C2C-inspired building; to ensure that this is the case, a certificate (eg Green Energy Label) should be requested from the electricity supplier. Note that electricity generated from waste incineration – often part of the offered “green” electrical supplies – is not considered regenerative from a C2C point of view.

The supply of green electricity may result in connection conditions (eg special tariffs for night-time electricity, which may require storage facilities in the building), which should be clarified with the supplier at an early stage, and considered in the design.

A purchase of green electricity from the grid alone is not considered sufficient for a C2C-inspired building; there must also be an own regenerative power generation.

For a building with a positive electricity self-sufficiency, externally generated electricity must be purchased from suppliers who produce renewable electricity themselves and do not just buy certificates.

8.4.2 Electrical storage

Due to the changing availability of regenerative energy sources, 100% coverage of many systems is only possible if the electricity produced is stored and called up again when it is required; suitable storage systems will have to be provided for this purpose. In this chapter, the most common technologies are evaluated for the C2C-suitability.

Batteries: Battery storage systems have gained market share in recent years primarily due to the reduced feed-in tariffs for regenerative energy. Currently, lithium-ion batteries and lead-acid batteries (gel or acid) as well as redox flow batteries are mainly used.

Aquion Energy used to offer a *Cradle to Cradle Certified*TM Bronze Level Salt Water Battery; however, at the time writing, the company is in the process of reorganising after bankruptcy and the certificate has expired. If the certification is re-gained, this technology would be a promising option.

Without C2C-certified batteries, lead batteries are currently well suited for C2C-inspired buildings because of their recycling rate; they have to be optimised for the technical cycle, since lead is on the “Banned List “ of the C2CPII for the biosphere. This means that lead batteries are not yet completely following C2C criteria, but due to the high recycling rate they are certainly a technology that can be used in C2C-inspired buildings.

If the recycling rate of the other technologies was increased, these would also be suitable for C2C-inspired buildings; however, the installation of redox flow batteries in single-family houses is still not economically viable in most cases, due to the increased maintenance requirements, the initial investment costs, and the specific requirements for the battery room due to large quantities of acid.

An interesting option is the re-use old car batteries in buildings. This has already been done in various projects (eg Efficiency House Plus in Berlin, Germany or the Arena in Amsterdam, Netherlands); it is not yet a fully C2C-inspired solution, as the used batteries are not yet optimised according to the C2C concept, but it can be a good intermediate step, extending the lifetime of the batteries.

Charging of electrical devices: One way of storing energy is to charge electrical devices, eg for electromobility; it would have to be examined to what extent the charging period could be adjusted to the time at which the surplus energy is available.

The C2C materiality would in principle also have to be met by the used electrical devices, but these are outside the system boundaries considered here.

Ice storage: Although not obvious at first, ice or PCM storage can be used to (indirectly) store electrical energy by using excess electricity to generate cold, which is then tapped into by the building's cooling system.

An important limitation of this option is the availability of such a storage; it can only be used when cooling is also required (ie typically / mostly in summer), and only when surplus capacity of the cooling system is available (ie only in the evening / at night / in the morning). A combination with other storage technologies will therefore be necessary.

For further information on ice storage tanks (eg types, materiality), see chapter 7 "[Cooling systems](#)".

Hydrolysis: The surplus electricity can be used to generate hydrogen, which is then later converted back into electricity using a fuel cell or gas turbine.

The combination of these technologies is not yet economical at the time of the preparation of the guideline. First installations are in operation, but no extensive data is available yet (see project of Umwelt Arena AG in Spreitenbach¹⁴⁹).

Flywheels: Flywheels are used, for example, in regenerative lift drives; their size and design, however, make them unsuitable for storing energy for the entire building.

Compressed air reservoirs: Compressed air reservoirs are also considered as part of the discussion on energy system transformation and energy storage; however, due to their size and technology (eg use of turbines), they are not suitable for most buildings – the technology is rather apt for district-wide grids.

Water reservoirs: Water reservoirs can be used to store electricity when either water needs to be pumped into them or the water pressure is used to generate electricity; in most cases this will not be the case for buildings, so this is not discussed here.

Grid feed-in: One way of storing electricity is to feed it into the grid; in reality, although the electricity is consumed there immediately, it can then be called up again if required by offsetting the feed-in and consumption.

In principle, however, this is only postponing the problem; the utility suppliers are already struggling to ensure that the regeneratively generated energy is not consumed at the time of generation and are building their own energy storage facilities using the above-mentioned technologies. It is therefore preferable to install energy storage systems in the building itself and even offering it to be used by the grid to store excess energy.

That notwithstanding, a C2C-inspired building is beneficial for the resilience of the power grid and should therefore be grid-integrated.

8.5 System sizing

Once the systems have been selected, the usual specifications of the system design as well as the design criteria defined under “Design criteria and boundary conditions” apply.

Since many systems influence with other C2C criteria (eg economy; use of surfaces of the building envelope for daylight, ventilation, greening), initial focus should be on reducing consumption; only a supply of minimised consumption should be sought. By reducing consumption, the technical feasibility of a positive electricity self-sufficiency is also increased.

To reduce consumption, passive measures (use of daylight, natural ventilation, greening, etc.) should be prioritised.

8.5.1 Power generation

In the following paragraphs, some indications are given on the size and cost of installations.

Photovoltaics: In the best-case scenario, common photovoltaic modules achieve approx. 170...200 W/m² or 150 to 180 kWh/m² per year.¹⁵⁰ As already mentioned in the chapter on system selection, for most buildings – due to the ratio of envelope area to usable area – self-sufficiency cannot be achieved by photovoltaics alone.

Fuel cells: The Fuel Cell Initiative provides information on the models available on the (German) market in the moment, which are shown in extracts in the following table.

Manufacturer	Description	Thermal power	Electric power	Electrical efficiency	Overall efficiency	Price*
Vaillant	Series start postponed					
SolidPower	BlueGen	0.6 kW	1.5 kW	up to 60%	up to 85%	25,000
Junkers	FC 10-2 A23	0.6 kW	0.7 kW	45%	85%	25,500
Hexis	Galileo 1000 N	1.8 kW	1.0 kW	35%	95%	21,000
Viessmann	Vitaflor	1.0 kW	0.7 kW	37%	90%	20,000
Buderus	Logapower FC10	0.6 kW	0.7 kW	45%	85%	26,500

Table 13: Overview of list prices for fuel cell heating (as at 30.05.17) excluding installation costs

* Prices from manufacturer inquiries

There are also fuel cells available for larger projects; examples would be cell for a 2,450 m² university building (mixed use with laboratories, offices and classrooms), with a combined electrical and thermal output of 100 kW¹⁵¹ (area requirement: 12.3 m² height: 3,4 m)¹⁵² or for a 36-storey office building in London (20 Fenchurch Street¹⁵³) with an output of 300 kW (space requirement: 37.2 m²)¹⁵⁴.

8.5.2 Degree of self-sufficiency

Current examples show realistic degrees of self-sufficiency for solar-powered residential buildings of approx. 30% without storage and 60% with energy storage; a 100% self-sufficiency is so far only possible with very large systems and generally not economically viable.¹⁵⁵

For supermarkets with larger roof areas, self-sufficiency levels of between 40% and 80% can be reached without energy storage;¹⁵⁶ logistics buildings sometimes can even reach 100%, and very high self-sufficiency levels are also possible for exhibition halls – especially when energy storage is used. For office buildings, the degree of self-sufficiency will strongly depend on the use (energy density) and the shape of the building.

8.5.3 Storage

The design of the power storage depends on the desired solar coverage, the economy, the installed technology for regenerative power generation and the space requirements.

Ideally, all electricity is generated in the building and not directly consumed electricity is stored, but in summer there may be a surplus that cannot be stored.

Table 14 gives an overview of different sizes of storages used in practical examples for single-family homes, apartment buildings and office buildings; Table 15 compares the various battery technologies.

Table 14: Exemplary relationship between storage capacity and degree of self-sufficiency

Building type	Electricity consumption	Installed PV capacity	Storage capacity	Degree of self-sufficiency
Efficiency house Plus Műnnerstadt	8.590 kWh/a	23.8 kWp	10 kWh	36%
Plus Brieselang efficiency house	5.215 kWh/a	8.9 kWp	24 kWh	39%
More family house "Stadt-Aktiv-Haus" Frankfurt ¹⁵⁷	approx. 250,000 kWh/a	370 kWp	250 kWh	47%
Office building Barcelona ¹⁵⁸		25.5 kWp	106 kWh	

151 ZBT GmbH, 2016

152 Fuji Electric Review, Masakazu, & Yoshimi, n.d., p. 3

153 Renewable Energy Focus, 2017

154 Fuel Cell Energy Inc., 2013

155 Vogtmann & Deutsche Gesellschaft für Sonnenenergie, 2014

156 Agora Energiewende, 2016

157 Steinbeis Transferzentrum Energie-, Gebäude- und Solartechnik, 2018, p. 5

158 Valence Technology, n.d.

	Efficiency charge-discharge incl. battery converter	Energy density (cells)	Possible re-charge cycles	Energy-related investment costs	Special requirements
Lithium ions	80...85%	200...350 Wh/l	1.000...5.000	300...800 €/ kWh	None
Lead acid	70...75%	50...75 Wh/l	500...2.000	100...250 €/ kWh	Installation room must be ventilated
Redox flow	70...80%	20...70 Wh/l	> 10.000	300...500 €/ kWh	None

Table 15: Comparison of battery technology

Table 15 shows the prices of new battery systems. During the research for the guide, no information could be obtained on the costs of “second-use” battery systems, but it is assumed these would be more economic.

Examples for the required area needed for battery storages is shown in Table 16.

Product	Usable capacity	Dimensions L x W x H	m²/kWh
Tesla Powerwall (Lithium-Ion) ¹⁵⁹	13.5 kWh	0.74 x 0.14 m x 1.12 m	0.008
E3/DC S10 Pro Blackline (lithium ion) ¹⁶⁰	13 kWh	1.02 x 0.46 x 1.03 m	0.04
Volterion VRFB1 (redox flow) ¹⁶¹	10 kWh	1.2 x 0.64 x 1.95 m	0.08
Hoppecke sun Powerrack classic (lead gel) ¹⁶²	11 kWh	0.83 x 0.39 x 0.90 m	0.03

Table 16: Overview dimensions of different battery technologies

When using lead-acid batteries, the installation room has to be ventilated; the air flow rate depends on the used technology (open or closed). Lithium-ion batteries do not require their own ventilation system; depending on the individual country’s code, this might allow some reduction of material and energy consumption.

When installing lead-acid batteries, their high weight must be taken into account – if necessary, the space intended for their installation must be designed for a higher load capacity.

159 Tesla Inc., n.d.

160 Pichler E-Tech, 2018, p. 11

161 Volterion, n.d.

162 Hoppecke GmbH, 09.15

8.5.4 Distribution networks

When designing electrical distribution networks within buildings, the C2C demand for 100% renewable energy means that energy savings are of secondary importance; the networks in C2C-inspired buildings would therefore have to be designed for lower material consumption within the framework of the applicable standards. However, as long as the cables meet the C2C material criteria, this criterion would also be omitted, and the systems can be designed purely according to economic considerations.

Due to the increased use of direct current components in buildings (PV systems and batteries), there are discussions as to whether a complete or partial switch to a direct current grid offers advantages. This is supported by the increased number of direct current consumers (laptops, smartphones, LED lighting, etc.).

From a C2C perspective, this would make sense in cases of complete self-sufficiency and integration of all technologies, as this would eliminate converters (and thus material); in general, from a C2C point of view there is no preference for one the technologies (DC or AC) – in each case it should be evaluated which technology is most compatible with the C2C objectives.

8.5.5 Lighting

The lighting of the building is to be designed in accordance with the highest standards of comfort and safety; for orientation purposes, the standard EN 12464-1 Lighting of work places, SPEC 67600 for biologically effective illumination and LEEDv4 building standard guideline from the document “LEEDv4 for Building Operations and Maintenance” may be used¹⁶³.

Because of the demand for 100% renewable energy supply, the well-being of the user ranks above energy efficiency; however, following the C2C mindset, the lighting standards required for the comfort of the user are then to be realised with the minimum number of luminaires required and minimum material costs – having an aesthetic lighting concept is not a C2C requirement.

8.6 Material selection

For the components of electrical systems, there is currently little possibility to insist on *Cradle to Cradle Certified*TM or inspired materials, manufacturing processes or biodegradability; however, it would help the market spread of the concept to ask manufacturers for information – which could lead to a rethinking on their side.

An example of this is lighting; manufacturers such as Philips offer the service of lighting (“pay-per-lux”) instead of luminaires, ie they provide the luminaires, replace defective light bulbs and take everything back for recycling when the service contract expires.¹⁶⁴ Such an approach would be in line with C2C, at least as far as the basic idea of the “material bank” is concerned.

It would probably also help if MEP designers cooperated with manufacturers to review and pilot (even if only in a part of the installation) C2C-inspired products – this could lead to a rethinking and the development of new products, materials, or construction methods.

8.6.1 Cables

Many cables contain PVC in their sheathing (according to DIN standard all cables with a Y in the description, and thus eg all NYM cables – the current market standard). These cables are not permitted according to C2C criteria, since PVC is on the “Banned List” for both the biological and the technological cycle; in the event of fire, toxic acids and acid vapours are produced by PVC materials.

There are already halogen-free (ie PVC-free) alternatives on the market; the tender documentation should specify that halogen-free cables are to be used as far as possible and that exceptions must be justified.

The only *Cradle to Cradle Certified*TM cables in the moment come from Hueson Wire & Cable in the USA; the Enviro-WireTM product line has achieved the silver level.

In principle, it would be desirable to reduce the amount of cable material used, but in view of the high recycling rate of cables, this is secondary to other criteria, as long as cables with PVC-free insulation are used.

8.6.2 Cable trays

Cable trays are usually made of galvanised sheet steel. The material is generally said to have good recyclability^{165,166} but the production is energy intensive. A detailed statement on how qualitative this recycling process is and whether C2C criteria are achieved is not part of this guide. However, galvanized steel sheet is not on the “C2C-Banned-List”, and with ZINQ there is a zinc plant whose zinc and production process is *Cradle to Cradle Certified*TM (Bronze Level); galvanized steel sheet can therefore in principle be used in C2C-inspired buildings.

¹⁶⁴ Philips, 2015

¹⁶⁵ ‘Verzinkter Stahl - WECOBIS - Ökologisches Baustoffinformationssystem’, n.d.

¹⁶⁶ ‘Forum | Nachhaltiges Bauen • Baustoffe • Ökobilanz Zink’, n.d.

There are also GRP cable trays on the market; this is a composite material that has a very poor recyclability and therefore does not meet the C2C criteria. Since GRP is a mixture of different materials, it is not generally to say whether the used materials are on the C2C Banned List.

There are no *Cradle to Cradle Certified*TM or similar cable trays at the time of writing.

8.6.3 Cable ducts and conduits

Many cable ducts and conduits contain PVC, which is not permitted in a C2C-inspired building, since PVC is on the C2C Banned List for both the biological and the technological cycle, and in the event of fire, acids and acid vapours are produced by PVC materials.

Halogen-free alternatives are on the market and to be used for C2C-inspired projects; however, whether these are 100% C2C could yet be clarified yet. Aluminium tubes are easy to recycle and can therefore be regarded as a sensible alternative.

*Cradle to Cradle Certified*TM cable ducts and empty conduits did not exist at the time of writing; as a result, the use of cable ducts and conduits should be reduced to a minimum (eg by establishing shortest possible routes and optimising duct sizes, or by surface-mounted installations).

8.6.4 Cable connections

Cable connections (Wago connectors, Lyster connectors, flat plugs, etc.) tend to be simple; they usually consist of a metal part that is sheathed in insulating plastic.

There are still no *Cradle to Cradle Certified*TM cable connections or known cable connections manufactured with the same qualities, it is not yet possible to make a recommendation for a particular type of cable connection; for a C2C-inspired building, they are to be selected by their ease of disassembly, ie separating plastic from metal.

8.6.5 Supports and fixings

Support materials for cable trays and fixings for pipes are mainly made of stainless steel, galvanised sheet steel or aluminium, so they generally comply with the C2C principle due to their recyclability and dismantlability, although the high energy consumption during their fabrication is a negative factor.

Special alloys and coloured lacquers should be avoided as far as possible. If certain colourings or fire protection classes are specified, the material composition and recyclability of the corresponding materials should be checked for compliance with C2C criteria.

Cable ties are a disposable product that cannot be separated non-destructively; the material must therefore be designed for the technical or biological cycle. Cable ties are generally used, among other things, for better clarity in cable trays but their excessive use also makes them difficult to dismantle. As *Cradle to Cradle Certified*TM cable ties are not currently available, the use of cable ties in C2C-inspired buildings should be restricted or replaced by steel/aluminium cable brackets where fixings are really needed.

8.6.6 Fuses

When selecting fuses, the safety of the user has priority. There are no *Cradle to Cradle Certified*TM or C2C-compliant fuses yet, nor is there any technology that is preferred from a C2C perspective – reduced consumption and efficient use of the technology is the most appropriate approach.

There is a recycling system for NH and HH fuses that recycles copper and silver; the residual materials (ceramics, quartz sand, other plastics and metals) are downcycled as slag in road construction.¹⁶⁷

8.6.7 Switch cabinets

At the time of writing, there are no switch cabinets that have been *Cradle to Cradle Certified*TM or manufactured according to C2C criteria.

Typically, switch cabinets are made of powder-coated steel sheets. Coatings are generally not optimal according to C2C criteria; a separation of the materials by material type may still be possible, but further use of the materials, especially the coating material, is no longer possible – the powder coatings are currently not designed for the bio- or technosphere. For this reason, switch cabinets made of stainless steel, galvanised steel or aluminium would be preferable according to C2C criteria.

As the materials are not yet recyclable according to C2C criteria, the longest possible use of the cabinets and a reuse in other projects should be aimed for.

Switch cabinets can also be made of plastic. If they are made of plastics that meet C2C criteria and are of a single grade, they can also be a good alternative; however, currently mostly glass-fibre reinforced PE is used, which does not meet the C2C criteria due to its poor recyclability; no other plastic enclosures are known to meet the C2C criteria so far, either.

8.6.8 Switches & sockets

For the selection of switches and sockets, their materiality should be considered. As with the other components, at least halogen-free products must be used. *Cradle to Cradle Certified*TM products are only available from Byrne at the time of writing this guide, but Byrne does not yet offer a complete collection.¹⁶⁸

Information on the material of switch and socket outlet ranges is currently still difficult to find. So far, manufacturers have provided only very little information about the

¹⁶⁷ NH/HH-Recycling e. V., n.d.

¹⁶⁸ Products Innovation Institute, n.d.

material and if so only that it is plastic and mostly thermoplastics. A more precise definition of the materials, whether they are suitable for C2C, or at least halogen-free is not yet clearly stated by the manufacturers.¹⁶⁹

Because of the visibility of the elements, project-related enquiries to manufacturers would be particularly helpful in this case – this could possibly lead to a rethink.

8.6.9 Luminaires

Although lighting is offered as a service (which is close to C2C use), no *Cradle to Cradle Certified*TM luminaires are available at the time of writing. This development could be accelerated by asking the manufacturers questions and by using leasing concepts (Philips “Pay-per-lux” and BB-Lightconcepts).

For the luminaire bodies, metal parts are to be preferred for C2C-inspired buildings; a confirmation of the aptness for disassembly should be requested from the manufacturers. Due to the corresponding recycling problems, painted or coated surfaces should be avoided, and luminaires with frames made of stainless material should be used.

The use of energy-saving lamps containing mercury should be avoided, as mercury is on the “Banned List for Materials” for biological and technical cycles.

Due to its high energy efficiency and long life, LED technology is to be preferred as an intermediate solution, although this technology is not yet optimized for C2C either – at the time of writing, there was no *Cradle to Cradle Certified*TM LED lamp. However, there is a luminaire system from BB-Lightconcepts which is *Cradle to Cradle Certified*TM (Bronze Level) and suitable for LED lamps; there are also “Product as a Service” models available (this has been implemented in the Venlo City Hall Building for the underground car park).

8.6.10 Batteries

Of the current battery types, lead-gel batteries are currently the most recyclable; the recycling rate for lead-acid batteries is 85.1% (2015¹⁷⁰). C2C-recycling is currently not available for any battery technology.

The recyclability of lithium-ion batteries still needs to be significantly improved – the recycling rate is currently below 60%¹⁷¹.

Whether redox flow batteries are to be recommended according to C2C criteria depends on their electrolytes. Currently the manufacturers do not offer information on the materials used, which does not allow a final statement on the C2C capability of the technology. Research is currently being carried out on electrolytes from renewable raw materials such as lignin¹⁷², which would be promising for meeting C2C criteria.

The only *Cradle to Cradle Certified*TM battery comes from Aquion Energy. The so-called salt-water battery is free of toxic substances and not flammable; a salt-water

169 Checked: Gira, Junker and Hager

170 Umweltbundesamt, 2017

171 IHK Braunschweig, n.d.

172 Paul, 2017

solution is used as electrolyte. An advantage is the possibility of a deep discharge. The energy density is currently not as high as with lithium-ion batteries; this can be improved by further development. This technology is used in Arup's "Circular Building" project; unfortunately, it is currently not available, as Aquion Energy is in the process of resuming production after a temporary insolvency. Due to the safe and non-toxic materials, this technology can make a major contribution to a C2C power supply.

It is possible to install used lithium-ion batteries from electric cars in buildings. The re-used batteries cannot store as much energy as new ones and are no longer interesting for electric vehicles; for building applications, however, the lower power spectrum is still sufficient.

8.6.11 Transformers

There are currently no transformers that are *Cradle to Cradle Certified*TM or have been proven to meet the C2C criteria. From a C2C point of view, dry or vacuum-insulated transformers with non-glued cores are the preferred technology; oil-insulated transformers are not commendable because of the possible formation of hazardous materials.

Due to the high metal content, transformers are collected and recycled free of charge by special services, so that a high recycling rate can be assumed (it should be ensured that the oils are disposed of as pollutants); the transformer size should still be optimised regarding energy and material consumption.

8.6.12 Fuel cells

A statement about the materiality and recyclability of a fuel cell is difficult to make due to a lack of data; the recyclability is not covered in the publications of the producers in the moment. At the time of writing, no *Cradle to Cradle Certified*TM fuel cells were available, or any that have been proven to meet the C2C criteria.

Solid oxide fuel cells (SOFCs) appear more difficult to recycle due to the high operating temperature and the resulting higher material requirements; however, this is initially only an assumption based on limited information available so far and needs further investigation.

In the context of the research for this guideline, only a recycling project for PEM fuel cells could be found (react – Recovery and Reuse of Precious Metals from Fuel Cells); the focus here is on the recycling of the precious metals contained in the stack membranes (especially from the platinum group). The components are separated after the stacks have been dismantled: Membranes, bipolar plates and other materials (housings, etc.); after their separation, the focus is on the extraction of the precious metals.

Processes are therefore available and precious metals are (also economically) recyclable; further investigations are necessary to be able to recycle the remaining materials and, above all, to create closed loops. Furthermore, the specified recycling methods must be checked for their impact on the environment.

Based on the results, PEM fuel cells with an open stack structure are to be preferred for their recyclability; however, this applies under reservation – further information is necessary, as well as a detailed consideration of the recycling process.

8.6.13 Photovoltaic modules

Photovoltaic modules usually consist of photovoltaic cells inserted in glass or polycarbonate; the glass or polycarbonate is usually framed in a metal frame.

The metal frames are easy to recycle; it should be checked how the glass / polycarbonate is framed – screw connections are preferable to gluing.

There is only one company that manufactures *Cradle to Cradle Certified*TM PV modules (Sunpower Corp.; Silver Level); it uses glass as a cover for its modules.

Information on the recyclability of polycarbonate modules is currently not available. Polycarbonate is used in a large number of mixtures depending on their use; this does not allow a general assessment, either.

Due to the lack of information on polycarbonate and the use of glass in the only *Cradle to Cradle Certified*TM PV modules, it can be assumed that glass modules are currently more suitable according to C2C criteria; however, this is not a final statement, as the glass modules are currently still far from being qualitatively recycled according to C2C criteria.

Research is currently being conducted into recycling processes for PV modules (eg shock wave recycling from Fraunhofer ISE with Impulstec GmbH). The results published so far indicate that new technologies will soon allow glass to be recovered at a high grade; so far, only downcycling (use for glass wool, cellular concrete and flat glass) is possible. Plastics cannot yet be recycled, and silicon wafers can only be recycled using a very costly thermal process.¹⁷³

Which PV technology (amorphous / polycrystalline / monocrystalline) is used will depend on the specific case. Crystalline cells use more energy and more material (crystalline cells are cut out of blocks, producing waste); however, their lifecycle is considerably longer than that of amorphous cells, and they produce significantly more energy, and all have a positive energy balance of embodied energy to energy yield. Given the typically limited surface available, a technology with a high yield per m² should be used; given the use of toxic materials and rare earths in their production, certified panels should be given preference.

173 Kernbaum & Hübner, 2013

8.6.14 Wind turbines

Wind turbines consist mainly of the rotor blades, the converter, the mast and the foundation.

Rotor blades are usually made of GRP; while this is not a desirable material from a C2C point of view, there are currently hardly any alternatives, especially for larger systems – metal rotors are too heavy and cannot withstand the material stresses that occur in operation.

The converters are largely made of metal and are, in principle, easily recyclable (see the comments on transformers).

Nowadays, masts are almost exclusively made of metal; in principle, this means that they are highly recyclable. However, a polyurethane lacquer is usually used as the coating; recovery of the lacquer will not be possible in the existing recycling processes, so that it should actually be designed for the biosphere.

The foundations are normally made of reinforced concrete, which has a limited recyclability; in their construction, the use of recycled materials should be ensured.

At the time of writing, no *Cradle to Cradle Certified*TM wind turbines were available, or any that have been proven to meet the C2C criteria. When selecting the wind turbines, it should be ensured that the above factors for C2C materiality is are optimised.

8.6.15 Generators

Generators are largely made of metal and are more or less completely demountable; manufacturers offer long-term maintenance programs that keep the generators running for a long time.

Wear products such as seals, lubricants and coolants must be designed for the technological cycle; this is to be requested from the manufacturers in each case.

At the time of writing, there were no *Cradle to Cradle Certified*TM generators available on the market, or any that have been proven to meet the C2C criteria.

8.7 Construction methods

In general, care must be taken to ensure that the components of power installations can be disassembled as easily as possible; the basic rules of “Design for Disassembly” must be adhered to.

Surface mounting with cable ducts or pipes is to be preferred for walls. For floors, raised or cavity floors are a good way to meet the “Design for Disassembly” criteria as well as the C2C criteria; the construction of the raised and cavity floors must comply with the C2C criteria for construction in chapter 14 “Construction Methods”.

Cast-in installation in concrete or flush-mounted installation in the plaster of brick walls should only be carried out if no other option is available; the connections created by the different types of material (eg flush-mounted box and gypsum, or empty pipe and gypsum, pipes poured in concrete etc.) make the separation of the components impossible, so this construction type leads to downcycling of many components. A separation according to material type can no longer be achieved, or only at great expense in terms of time, energy, ecology or money, which means that this construction method does not comply with the C2C principles.

Flush-mounted installation in dry construction walls or installation in raised floors allows easier installation, conversion and better dismantling at the end of the useful life or for modifications and refurbishments. The decisive factor for fulfilling the C2C criteria here is the separability of the connections; the cables are not plastered in, which enables separation by type and thus complies with the C2C principles.

9. Extra-low voltage (ELV) systems

9.1 Aims and evaluation criteria

9.1.1 Overview

C2C aim	There are no unique aims for ELV systems - they only support the C2C aims of other systems
C2C minimum criterion	Employed materials and construction methods follow C2C criteria
C2C no-go criterion	Use of materials on the “Banned List” of the C2CPII
C2C material criteria	See chapter 13
C2C construction methods	See chapter 14

9.1.2 Explanation

The only C2C criterion that ELV systems directly influence is that regarding materials; they also have an influence on electrical energy consumption, but this is already covered under “Electrical installations”, so no criteria unique to ELV systems were established.

When they are considered in a C2C context, ELV systems should be considered as products whose materiality should be optimised; this could include a critical consideration of the necessity of systems or elements - fewer elements and fewer systems require less material and energy.

It should also be considered in an overall context whether the facilities can contradict or support the objectives of other technology groups; for example, efficient planning of racks in a data centre would help achieve the power consumption objectives and efficient planning of access control would facilitate disabled access.

9.2 Design criteria & boundary conditions

In principle, there are no specific design criteria; however, during the establishment of the brief it should be critically questioned whether all systems are necessary, and the aims of reducing material and energy consumption should be defined.

9.3 System selection

The system choice should be based on minimising material and energy consumption (as few elements as possible, as short cable routes as possible); should there be a contradiction between the two, priority should be given to reducing material consumption in the case of peripheral elements, while priority should be given to energy consumption in the case of cables, which are in principle well recyclable.

An example of such a system selection could be a VOIP system that saves cables.

It should also be considered whether second-hand devices can be used, or whether the selected systems are reusable; this would also be a criterion for the system design.

It is understood that some ELV systems (eg fire detection or fire alarm) are governed by code; clearly the compliance with code has priority over C2C criteria.

9.4 System sizing

As soon as the systems have been selected, the usual specifications of the system design as well as the design criteria defined under “Design criteria and boundary conditions” apply.

During design, particular attention must be paid to the aptness of the systems for repair, retrofit and disassembly of the systems; this also applies to sizing the corresponding rooms, risers and cabling infrastructure. ELV installations are particularly prone to technical development and change over the lifecycle of the building, and sufficient size and access should be provided.

In the context of system design, it would be helpful to make manufacturers aware of the C2C issue (certification of elements and materials, list of materials used, dismantlability) and to favour manufacturers making efforts in this area.

9.5 Material selection

The C2C criteria for materials must be followed (see chapter 13 “[Material](#)”).

At the time of writing, there are no ELV systems or elements that are *Cradle to Cradle Certified*TM or constructed according to C2C criteria.

When selecting materials, pressure should be put on manufacturers, and material – especially in the case of casings of equipment – should be preferred which makes at least an effort towards C2C certification or material criteria.

It would probably also help if MEP designers cooperated with manufacturers to review and pilot (even if only in a part of the installation) C2C-inspired products – this could lead to a rethinking and the development of new products, materials, or construction methods.

Information on cable trays, fixings etc. is already contained in the chapter 8 “[Electrical installations](#)”; here only specific installations of telecommunications or information technology installations are covered.

9.5.1 Peripherals

Fire detectors, loudspeakers, cameras, motion detectors, card readers, etc.:

At the time of writing, there are no peripherals that have been certified or created according to C2C criteria.

9.5.2 Telephones

For telephones, there are currently the first initiatives that are at least striving for fair production and reparability of the systems. Fairphones and Shiftphones are the most fairly produced smartphones to date; however, both do not yet fulfil the C2C criteria.

9.5.3 Data cables

To reduce material consumption, structured cabling networks can be used that transmit data from several systems in a common network and thus require fewer cables.

Fibre-optic cables are more complex components, whose materials are difficult to separate; the fibre itself can be recycled, but the cable is a composite. Although EU projects such as L-Fire (Long Fibre Recycling) have been carried out to exploit the recycling potential of fibre optic cables, a comprehensive coverage for recycling is not yet available.

Copper cables, on the other hand, are in principle recyclable, and reach a high recycling rate because of the price of copper; however, copper recycling is not yet carried out using renewable energy. If, however, this is again put in relation to the energy and resource requirements for fibre optic cables, which are also made from primary material, copper cables are to be preferred where technically feasible (eg for speed, bandwidth, or transmission distance), even if this means increased material requirements during installation; the installation of fibre optic cables is to be avoided as far as possible following C2C criteria.

As with the power cables (chapter 8.6.1 “Cables”), there are also data cables with at least halogen-free sheathing. These are preferable to cables using PVC.

There is currently only one company offering *Cradle to Cradle Certified*TM power cables; data cables are not included in the moment.

9.5.4 Cable connections

Information on this area can be found in chapter 8.6 “Material selection” in the chapter 8 “Electrical installations”.

9.5.5 Cable ducts and pipes

Information on this area can be found in chapter 8.6 “Material selection” in the chapter 8 “Electrical installations”.

9.5.6 Cable trays

Information on this area can be found in chapter 8.6 “Material selection” in the chapter 8 “Electrical installations”.

9.5.7 Fixings

Information on this area can be found in chapter 8.6 “Material selection” in the chapter 8 “Electrical installations”.

9.5.8 Controller

Information on this area can be found in chapter 8.6 “Material selection” in the chapter 8 “Electrical installations”.

9.5.9 Switch panels

At the time of writing, there are no switch panels that have been certified or created according to C2C criteria.

9.5.10 Switch cabinets

Information on this area can be found in chapter 8.6 “Material selection” in the chapter 8 “Electrical installations”.

9.5.11 Server cabinets

Information on this area can be found in chapter 8.6 “Material selection” in the chapter 8 “Electrical installations”.

9.6 Construction methods

The corresponding information in chapter 8 “Electrical installations” applies accordingly.

According to C2C, (detachable) plug connections are to be preferred to soldered connections for cable connections; they should be selected to be robust and have a long expected lifetime.

For later expandability, additional cable lengths must be provided for each data connection; the initially increased material costs are offset in the course of the life cycle by savings in the total replacement of the affected cable.

ELV installations are particularly prone to technical development and change over the lifecycle of the building, so sufficient extra space for distribution and access for replacement should be provided.

10. Vertical transport systems

10.1 Aims and evaluation criteria

10.1.1 Overview

C2C aim	There are no unique aims for vertical transport systems - they only support the C2C aims of other systems
C2C minimum criteria	Optimisation of energy consumption and material usage
C2C no-go criteria	Use of electricity from fossil fuels; use of materials on the “Banned List” of the C2CPII.
C2C material criteria	See chapter 13
C2C construction methods	See chapter 14

10.1.2 Explanation

The only C2C criterion that vertical transport systems directly influence is that regarding materials; they also have an influence on electrical energy consumption, but this is already covered under “Electrical installations”, so no criteria unique to vertical transport were established.

When they are considered in a C2C context, vertical transport systems should be considered as products whose materiality should be optimised; this could include a critical consideration of the necessity of systems or elements - fewer elements and fewer systems require less material and energy.

Conveyor systems such as lifts etc. are mandatory in many types of buildings to provide disabled access; this is in line with the C2C criterion “celebrate diversity” to support and expand, and not to neglect due to material costs or increased energy consumption.

In multi-family houses, lifts can have a large influence on the ecological footprint of the MEP (according to Weißenberger TU Munich, approx. 12...44% – very dependent on the technology standards of the individual building, eg air-conditioning or not); in buildings with a higher density of installations (eg offices), this percentage is lower, but the material input of these systems cannot be neglected.¹⁷⁴The energy use of a lift system accounts for approx. 5% of the total energy consumption of a building;¹⁷⁵ this is also strongly dependent on the use of the building, and here, too, an optimisation would be desirable (eg by co-locating stairs and lift shafts, and making the stairs visible and accessible from the lift lobby).

10.2 Design criteria & boundary conditions

During the establishment of the brief, the no-go and minimum criteria should be listed – the objective of material and energy savings should be clearly identified.

The design criteria can have an influence on the material use – due to higher requirements on the quality of the lift systems (waiting time; car size, transport weight), more or larger lifts may be required. The same applies to the travel time, which may increase energy consumption. It should be ensured that an appropriate standard is established in each case.

The highest possible energy efficiency class (Category A of VDI 4707 Part 1 (p. 13)) is to be applied for lifts.

The desired economy in the implementation of the C2C objective may result in further design values, eg optimisation of the space requirements of the lift cores, etc.

10.3 System selection

The most basic system selection would be to choose between walking and taking the lift; the design of the building – in principle a responsibility of the architect, but influenced by the designer of the vertical transport systems – should support the former. By designing adequate fixed stairs in the right location, the need for lifts (or at least their size) can be reduced.

For vertical transport systems themselves, there are relatively few system choices; usually there is a system optimised for a particular use, and only within that system are there other choices which then fall under system sizing.

In this guide, lift installations are differentiated according to type (hydraulic or cable); the application (passenger, goods or freight lift) has no influence on the C2C assessment.

There are currently no *Cradle to Cradle Certified*TM or C2C-inspired vertical transport systems; the system selection should consider how to minimise material and energy use (as few elements as possible, consumption as low as possible, adapt systems to renewable energy generation).

If a decision has to be made between material consumption or energy consumption, priority should be given to the optimised use of resources, assuming that the vertical transport installations are supplied with electricity from renewable sources.

From a C2C point of view, C2C does not specify where the machine room of the lift system (if required) is located in the building; however, maintenance and dismantling must be as easy as possible.

A generic recommendation for a specific lift system for C2C-inspired buildings cannot be made; so far both main lift types have not been optimised according to C2C criteria. The selection depends very much on the requirements of the specific project (rise, load capacity, utilisation, etc.); according to C2C criteria, no technology is generally excluded.

10.3.1 Traction lifts

Traction lifts are most frequently used in residential construction¹⁷⁶; the same applies to office buildings. When selecting this system, it is important to decide whether to use technologies with or without a machine room. From a C2C point of view, there is no preference; the C2C criteria for materiality and construction must be adhered to in both cases.

Regenerative drive: In general, a regenerative drive – in which excess energy from braking and acceleration processes is fed back into the building's supply network via an inverter (see LVM Kristall Münster¹⁷⁷; manufacturer eg Schindler 5500) – is to be welcomed as an energy-saving measure; however, for each individual project it should be examined whether such a system offers advantages over a conventional system, eg if the additional material is warranted by the energy savings.

¹⁷⁶ Laasch & Laasch, 2013, p. 867

¹⁷⁷ Schindler Deutschland AG & Steeger, 2016

At the time of writing, there is no *Cradle to Cradle Certified*TM or similar quality regenerative drive for traction lifts; this means that the drive increases the negative footprint for material usage. According to Unger, the share of lifts in the energy consumption of buildings is rather low¹⁷⁸, while according to Weißenberger the share of lifts in the ecological footprint of the MEP is rather high.¹⁷⁹ It is therefore necessary to check on a case-by-case basis whether another component such as the regenerative drive actually has an advantage.

In buildings where the share of energy consumption in lifts is higher (eg office buildings or hospitals), this technology will make sense in most cases; where lifts are used rather sporadically, the technology will probably make less sense.

Hall call control: A hall call control allows the passenger to indicate where he or she wants to go when the lift is called; this allows the control to optimise the travel of the lifts, resulting in both shorter travel times and fewer lift trips. In principle, such a system is a pure efficiency measure, but also commendable from a C2C perspective.



Image 18: Arup use a “Hall call” system in their offices in London

178 Unger, 2015, p. 213

179 Weißenberger, 2016, p. 104

10.3.2 Hydraulic lifts

Hydraulic lifts are usually employed for low building heights (up to 20 m), or where a roof structure for a machine room is to be avoided. Hydraulic lifts are also used where particularly high loads have to be transported. One limitation is their speed, so that they are not suitable for higher demands on waiting times.

The different types (direct; indirect with pull piston or compression piston) are not considered in detail in this guide. At the time of writing, there are no systems for any of the types of construction that are certified according to C2C criteria or correspond to similar qualities; a statement as to which technology is more suitable for C2C is therefore not possible within the scope of this guideline.

It should be noted that here is a *C2C Material Health Certified*TM alternative for hydraulic oils: The hydraulic oil Environmax from Thyssen Krupp (for more information see [10.5 “Material selection”](#)) offers a biodegradable alternative to oils previously obtained from fossil sources. Whether this component is sufficient for hydraulic lifts to be preferred to cable lifts cannot be clarified within the scope of this guideline, but should be investigated in the future.

10.3.3 Escalators and travellers

At the time of writing, there are no escalators or travellers that have been *Cradle to Cradle Certified*TM or produced according to C2C criteria.

There is no escalator or traveller type that should be preferred or excluded according to C2C criteria; it should only be questioned critically whether the use of such a system is necessary at all.

10.3.4 Other conveyor systems

Further conveyor systems are for example facade access systems, pneumatic tube systems and automatic parking systems.

The different systems of the facade access systems are quite similar regarding their materiality (mostly metal), so currently no system is favoured or to be discarded from a C2C perspective. There is no *Cradle to Cradle Certified*TM technology or technology based on similar criteria; the systems are to be optimised for space and material consumption.

Automated parking systems are usually employed where creating the space for parking lots required by local code is difficult due to site constraints; as such, the systems contribute to less land use and to less material use for the building (typically concrete, plus excavation volume). The parking systems are mostly constructed of steel, which would have a higher recycling rate than the concrete; the energy use would not play a role as long as it is meeting C2C criteria, ie being supplied from regenerative sources. Automated parking systems are therefore considered a viable solution for C2C buildings; they should be selected and specified to meet C2C criteria.

10.4 System sizing

System sizing plays a special role in meeting the C2C criteria for vertical transport systems; it is here where material usage and energy consumption can be optimised.

It is common to ask manufacturers to design their vertical transport installations; however, manufacturers have no interest in reducing material input, so that design by independent designers is preferable.

In addition to a critical evaluation of the design criteria (“what quality is actually necessary for vertical transport?”), efficient design of the building layout has an influence on the number of lifts; a combination of several lifts in a block requires fewer lifts, and a line of sight to a staircase reduces the use of lifts for short distances. Here the object designers are to be informed and/or advised as early as possible in this regard.

When designing the lifts, the choice of door opening type can also influence the use of materials; centrally opening doors open faster and can influence the number of lifts by influencing the waiting time. The lift design should be optimised to reduce the number of lifts – which also results in cost and space savings.

When designing the lifts, care must also be taken to ensure that the installations can be repaired and dismantled. In this sense, it would be helpful to confront manufacturers with the C2C issue during the design phase (certification of elements and materials, list of materials used, dismantlability) and to favour manufacturers making efforts in this area.

Energy-saving technologies such as LED lighting and automated switch-off during standby should be considered in the design of lift cabins; for escalators or travellers, a reduction of travel speed or standby shutdown should be provided.

When using hydraulic lifts, the disposal of the hydraulic oil and the oil-tight execution of the various components must be considered; the use of a *Cradle to Cradle Certified*TM hydraulic oil can also bring economic advantages.

10.5 Material selection

When selecting and tendering the lifts, the C2C criteria for materials must be observed (see chapter 13 “Material”). Pressure should be put on manufacturers and preference should be given to products for which at least efforts have been made towards C2C certification or a list of materials.

It would probably also help if MEP designers cooperated with manufacturers to review and pilot (even if only in a part of the installation) C2C-inspired products – this could lead to a rethinking and the development of new products, materials, or construction methods.

Under certain circumstances, the choice of material (eg rope or belt) also influences the choice of system or the system design; this must be considered in the corresponding design phases.

Information on electrical cables, cable trays, fixings, etc. is already contained in chapter “[Electrical installations](#)”; here only specific elements of the conveyor systems will be dealt with.

10.5.1 Lift drive

As far as materials for lift drives are concerned, due to the market situation there is currently little possibility of insisting on *Cradle to Cradle Certified*TM materials, manufacturing processes or design for disassembly; however, it would help the market expansion of the concept to inquire from the manufacturers in each case – this could lead to a rethink.

At the time of writing, there are no drive units that have been certified or produced according to C2C criteria.

10.5.2 Lift cabin

In the lift car, electronic components such as the control panel, lighting and displays, as well as wall surface finishes are installed; the controls and lighting are dealt with in separate headings.

At the time of writing, there is no fully *Cradle to Cradle Certified*TM lift cabin. However, Thyssen Krupp offers four options where the wall cladding has a C2C Material Health Certificate in Bronze; however, these are only the steel construction and various components of the cladding.¹⁸⁰ The certification level is still very low and only in the material health category, but it is a first step.

As far as the equipment of lift cabins is concerned, it can generally be said that uncoated metal surfaces are preferable to painted or coated surfaces.

Galvanised steel sheets have very good recycling properties (C2C certification ZINQ) and can therefore be used in C2C-inspired buildings.

Mirror surfaces consist of a glass panel with a silver layer; often a protective varnish is applied in addition. It was not possible to find out in the course of the research for this guideline whether it is possible to recycle these substances by type, but it is questionable, so that mirror surfaces should be avoided as far as possible.

Wood panels are a C2C alternative only if the wood has been left untreated or only with substances designed for the biosphere. Glued wood is a downcycling of the wood and is not allowed according to C2C criteria, since a glue that meets C2C criteria is not yet available. Wood panels that meet the C2C material criteria are preferred over metal surfaces from a C2C point of view, due to the easier recycling.

From a C2C point of view, electronic displays that go beyond the mere function of the lift (eg information / advertising screens) should be avoided because of the amount of material required and the low recyclability.

10.5.3 Cabin lighting

The criteria for lift lighting differ little from conventional lighting (only by a lower priority of the physiological effect of light); more detailed information on this area can be found in chapter 8 “[Electrical installations](#)” under 8.6 “[Material selection](#)”.

10.5.4 Lift car frame

The car frame is largely made of metal, which indicates that it is basically recyclable; other components such as rope sheaves, safety gear, etc. are not considered in detail in this guide due to the small amount of material required. It would be preferable if the metal parts were made of stainless or galvanised steel and were not painted / coated.

As far as car materials are concerned, there is currently little possibility of insisting on *Cradle to Cradle Certified*TM materials, manufacturing processes or design for disassembly due to the market situation; however, it would help the market spread of the concept to inquire from the manufacturers in each case – this could lead to a rethink.

At the time of writing, there are no lift cars that have been certified or created according to C2C criteria.

10.5.5 Guide rails

The guide rails are usually made of steel, which is theoretically recyclable; however, this recycling process is very energy-intensive and cannot yet be carried out with renewable energy. For the designer, however, there are in principle no alternatives when it comes to material selection.

10.5.6 Counterweight

The counterweight usually consists of a metal frame filled with weights of either lead, concrete, grey cast iron or steel.

Since the counterweight must be designed for the technosphere, none of the materials are on the banned list of the C2CPII (lead is only not suitable for the biosphere; as a precautionary measure, however, it should still be avoided). Concrete as a composite material is difficult to accept as C2C-inspired, so a preference for steel or grey cast iron could be argued – although this would not be an exclusion criterion.

10.5.7 Buffers

According to EN 81-20, a buffer must be installed in the lift pit, which can cushion the lift car in an emergency. A distinction is made here between energy-storing and energy-consuming buffers.

Energy-storing buffers are used as attachment buffers for speeds < 1 m/s and are typically made of polyurethane; energy-consuming oil buffers are used for other applications.

Oil buffers are largely made up of metallic components (information on metal and C2C in the chapter 13 “Material”) where oil is used for energy absorption. If possible, bio-based and biodegradable hydraulic oil should be used.

Attachment buffers are mostly mono-material components; the elastomers commonly used are currently not optimised to C2C. Even if the buffers do not yet meet C2C criteria because the materials are not defined, the components are at least made of a mono-material, with an assembly surface mostly made of steel, which should allow recycling. In principle, use in C2C-inspired buildings is therefore possible.

10.5.8 Escalator / traveller handrail & balustrade

The frame of the balustrade is typically made of metal; there is little choice to be made. The lining can be made of plastic (plexiglass), glass or metal. Glass and metal both have good recyclability but high energy consumption. In the case of metal linings, the type of paintwork must also be considered. In the case of plexiglass, the question of material health and recyclability according to C2C criteria still has to be clarified. At the moment, glass panelling would be the preferred choice from a C2C point of view.

Handrails of escalators / travellers are currently a composite of several layers of fabric with a rubberized steel inlay, and have a service life of 4 to 7 years in operation.¹⁸¹ Due to the inseparable combination of different materials, the handrail does not meet the C2C criteria, but at the time of writing there is no *Cradle to Cradle Certified*TM or similar quality handrail for escalators, so there is no alternative.

10.5.9 Escalator steps

The escalator steps are made of die-cast aluminium or steel; both materials are theoretically easily recyclable, although this recycling process is very energy-intensive and cannot yet be carried out with renewable energy.

Mostly die-cast aluminium steps are used, as the lower weight simplifies the movement of the steps; this results in lower energy consumption and the possibility of reducing the size of the components needed to move the staircase.

Even though C2C criteria do not allow a general statement on the suitability of aluminium or steel grades, they currently appear to be the 'least disadvantageous' option.

No additional paint or coating should not be applied, due to the lack of recyclability and the reduced material quality.

10.5.10 Hydraulic oil

As an alternative to conventional hydraulic oils obtained from crude oil, oils on a renewable basis can be used. No hydraulic oil has been fully *Cradle to Cradle Certified*[™] to date; however, according to the manufacturer, the "BioBlend Enviromax 2.0 Biodegradable Elevator Hydraulic Oil", the first hydraulic oil for lifts to be 100% recyclable and plant-based (rapeseed) has a C2C Material Health certification in platinum (highest level).

10.5.11 Controls

Modern lifts require electronic controls; most of the functions are solved by programming and not by mechanical or electrical components. Due to the technical complexity of the electronic components, however, most of them currently do not meet the C2C criteria.

Due to the low cost of materials and the high energy saving potential, the use of such controls is acceptable in C2C-inspired buildings; modern control systems should be used to increase the capacity and thus reduce the energy consumption of the systems, and possibly even the number of lifts.

More detailed information on electronic components can be found in chapter [12](#) "[Building management / controls systems](#)".

10.5.12 Lift cables / ropes

Image 19: Belts instead of cables require no lubricants



Depending on the size of the building, the steel cables can account for a significant or the largest proportion of the material used in the lifts.

Steel ropes are the technology used in most cases. Steel is easily recyclable, but it is not yet possible to recycle steel using renewable energy alone. The material should therefore be used for as long as possible (and then reused); the highest possible strength class is a good fit.

A lubricant is used for the smooth operation of the lift cables. At the time of writing, there are no *Cradle to Cradle Certified*TM lubricants.

Instead of steel cables, Otis uses belts consisting of small steel cables coated with a polyurethane layer. These belts are considered to be environmentally friendly because they can be operated without lubricants; however, the C2C rating depends on the recyclability of the polyurethane, for which no information has yet been provided by the manufacturer.

The belts have a longer service life than steel ropes and would be preferable to steel ropes in this respect; whether this outweighs the use of the polyurethane layer could not be clarified during the preparation of this guide, due to the manufacturers' unwillingness to provide information about the material.

10.6 Construction methods

For all components, a good accessibility and dismantlability must be ensured. Compliance with relevant codes and regulations will already provide reasonable accessibility; a good part of the connections in the construction of the guide rails, the drive and the lift car frame are usually also screw connections, facilitating dismantlability.

It would be worth asking the manufacturer where pieces are welded, soldered, or glued, and where that can be avoided; most opportunities for improvement are usually in the visible parts, eg welding entrance frames or gluing finishes in the lift car (see also [“10.5 Material selection”](#)).

Often overlooked is the access to the lift motor room; it should be ensured that there is an appropriate route for transporting replacement parts to and from the room.

11. Usage-specific / specialist systems

This heading contains a wide range of systems, which are often designed for very specific applications:



Image 20: Fire protection systems



Image 21: Technical media supply systems



Image 22: Kitchen equipment



Image 23: Medical and laboratory equipment

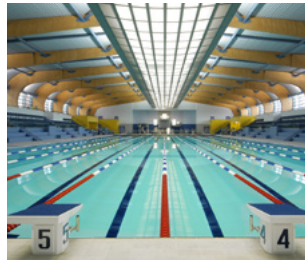


Image 24: Swimming pool systems



Image 25: Industrial washing and dry-cleaning equipment



Image 26: Industrial heating, refrigeration and ventilation systems



Image 27: Waste disposal systems

This guide does not cover all these systems; priority was given to fire protection systems, as these are used in practically every building; other installations (eg kitchen, laboratory, swimming pools) are only briefly covered and may need to be assessed in future versions of the guide, with water treatment installations assessed in chapter 3 “Water systems”.

11.1 Aims and criteria

11.1.1 Overview

C2C aim	There are no unique aims for the above specialist systems - they only support the C2C aims of other systems (eg energy use, material use, water treatment, etc.)
C2C minimum criterion	Optimisation of energy and material consumption
C2C no-go criterion	Use of materials on the “Banned List” of the C2CPII
C2C material criteria	See chapter 13
C2C construction methods	See chapter 14

11.1.2 Explanation

Of the C2C objectives, the use specific and process-engineering installations as technology in principle only influence material use and energy consumption - whereby the electricity supplying them is already treated under chapter 8 “[Electrical installations](#)”. Therefore, they are to be treated as products in the sense of a C2C consideration and must be optimized in their materiality and energy use according to C2C criteria.

The optimisation of materiality and energy use according to C2C criteria could include a critical consideration of the necessity of systems or elements – fewer elements and fewer systems require less material and energy and thus simplify the step towards a positive footprint of the building.

The only C2C criterion that specialist systems directly influence is that regarding materials; they also have an influence on electrical energy consumption, water consumptions and quality, heating, and air quality, but they are already covered under 8 “[Electrical installations](#)”, 3 “[Water systems](#)”, 5 “[Heating systems](#)” and 6 “[Ventilation systems](#)”, so no criteria unique to the above specialist systems were established.

When they are considered in a C2C context, the listed specialist systems should be considered as products whose materiality should be optimised; this could include a critical consideration of the necessity of systems or elements – fewer elements and fewer systems require less material and energy.

Of course, the C2C requirements cannot override the requirements of applicable codes or regulations. As an example, the safety of people in the building would clearly have priority over C2C criteria when designing a fire protection system; as it happens, this is also in the interest of recyclability, since damage caused by fires can significantly reduce the value of the components and make C2C-compatible recycling impossible. However, where alternatives exist within the framework of the fire protection concept, those which have the optimum material or energy consumption (with priority on material consumption) should be given preference.

The same applies to other specialist systems – their functionality is the driving factor and can only be optimised according to the C2C criteria; a restriction or even elimination of an entire function is not the aim of the C2C concept.

11.2 Design criteria & boundary conditions

The establishment of the brief should include the no-go and minimum criteria – the objective of material and energy use according to C2C should be clearly presented.

In principle, there are no specific design criteria; however, during the establishment of the brief it should be critically questioned whether all systems are necessary and the specific objectives of a material and energy use according to C2C criteria should be set out.

In safety-related systems such as extinguishing systems, a clear priority must be given to human safety; this should also be described in the brief.

11.3 System selection

The choice of system will mainly depend on the specifications of the fire protection concept; it would be worth questioning whether the extended use of extinguishing systems could reduce requirements for increased material consumption in other areas (creation of fire compartments).

A further question would be whether the fire risk can be completely or partially avoided by passive and active measures (eg early detection systems, avoidance of fire risks such as spark generation) of the extinguishing systems; here a risk analysis could possibly be carried out with the aim of finding solutions for risk reduction that save as much material as possible.

This chapter therefore only deals with system selection where there is actually a choice according to the fire safety concept; in the area of material selection it is examined more closely whether there is optimisation potential within the various systems according to C2C aspects, without reducing the performance of the systems.

11.3.1 Extinguishing systems

There are currently no *Cradle to Cradle Certified*TM or C2C-inspired fire extinguishing systems; therefore, the system selection must currently be designed to use as little material and energy as possible, and attention must be paid to the recyclability of the materials – the implementation of C2C is simplified in a system that is as simple as possible from a technical and material consumption point of view.

If a choice has to be made between material consumption or energy consumption, priority should in principle be given to the optimised use of materials; it can be assumed that the installations are only in operation in exceptional cases and therefore do not play a role in the overall balance of energy consumption of the building.

11.3.2 Manual fire fighting

Hand-held fire extinguishers: For hand-held fire extinguishers, only a discussion about the fire classes specified in the fire safety concept is possible (ie if a different, more C2C-suitable class can be used); there is not really any choice within the fire classes, except for the extinguishing foam for class F (see the corresponding information in the subchapter [11.5.6 “Extinguishing agents”](#)).

Hydrant systems: There are clear regulations for the selection of hydrant systems; there are no preferences from a C2C point of view.

Safety showers: Safety showers are special applications that are basically to be regarded as water systems; see the corresponding chapter [3 “Water systems”](#).

11.3.3 Automatic fire-extinguishing systems

Sprinkler systems: In principle C2C does not specify whether wet, dry or wet/dry piping systems are to be preferred. Dry systems are normally used either to protect the water in the pipes against freezing or to reduce the risk of accidental activation (eg by breaking a sprinkler head); due to the larger sprinkler tank required for dry systems, more material is consumed there, but this may be outweighed by saving on the thermal insulation of the sprinkler pipes or trace heating – which is project-dependent.

The necessity of fire water retention to avoid the release of pollutants contained in the water used for extinguishing a fire regulated by code and defined in the of the fire safety concept, and thus cannot be influenced by the C2C concept.

Fire pumps can be electric or diesel-powered. Where electric pumps can be operated with regenerative energy (eg with a so-called “sprinkler circuit”), these would be preferable (also because of the material consumption); in the case of diesel pumps or electric pumps operated with electricity from emergency generators, the fuel would have to be considered (see corresponding chapter 4 “Gases and fuels”).

Water mist extinguishing systems: In a water mist extinguishing system, a spray of very small water droplets is used as extinguishing agent; thus, a large amount of energy is quickly extracted from the fire and the cooling effect of the extinguishing agent (water) can be optimally used. With this system, the amount of extinguishing water and thus also the water supply, the size of the pipes and potential damage caused by the water extinguishing agent can be reduced; therefore, such a system – if it has been approved by the fire protection expert and the authority – is to be favoured for C2C use.

Deluge systems: This type of system is used for rapid flooding of rooms or objects particularly at risk of fire, and for protecting tanks or similar equipment to prevent impermissibly high temperatures.¹⁸² A distinction can be made between single-phase systems, which only extinguish with water, and multi-phase systems, which use additives; for C2C-inspired buildings, single-phase systems are to be preferred if the fire safety concept allows it.

Stationary foam extinguishing systems: These are used where flammable liquids are to be expected, eg in warehouses, tank farms, landing areas, etc. There are no C2C specifications for the system, but due to the environmental impact, fluorinated extinguishing foams should be avoided in C2C-inspired buildings if the use of the building allows it.¹⁸³

Gaseous fire-extinguishing systems: Gaseous fire-extinguishing systems are used in cases where other extinguishing agents (water or foam) would cause major damage, such as high-value technologies, cultural assets, switching and control systems, laboratories, etc.

When triggered, inert gases are introduced into the room, and the resulting reduction in the atmospheric oxygen concentration extinguishes the fire. An advantage of these systems is the fact that the extinguishing agent is electrically non-conductive and completely residue-free; however, due to the risk of suffocation when triggered, they can only be used in areas that are not permanently occupied. The material consumption (storage of the inert gas) is also too high for larger areas, so that this solution is limited to specific areas.

CO₂, nitrogen and noble gases (argon) or mixtures of these gases (eg inergen, argonite) are used as inert gases (non-flammable gases).¹⁸⁴ Further information on the extinguishing media can be found in the subchapter [11.5 “Material selection”](#) under [11.5.6 “Extinguishing agents”](#).

According to C2C criteria, a gas extinguishing system is not a no-go criterion; however, all components must meet C2C criteria. The risk of suffocation from the use of extinguishing gases is a negative factor; all safety requirements must be observed to minimise this risk.

Chemical extinguishing systems: In chemical extinguishing systems, oxygen is not extracted from the combustion chamber, but the flame is cooled until it is no longer possible to maintain combustion. As there is no removal of oxygen, the extinguishing agents do not lead to a suffocation hazard.

Chemical extinguishing agents (eg HFC-227ea, HFC-23, Novec™ 1230) are used for this type of system; the technology is used especially for electronic components such as computer centres, etc.

According to a study by the German Environment Agency (Umweltbundesamt, UBA), the use of extinguishing agents can have negative effects: Although the extinguishing agents have no ozone depletion potential and the toxicology of the extinguishing agents themselves is considered acceptable by UBA, they have the same greenhouse potential as carbon dioxide and during the extinguishing process corrosive and toxic decomposition products can occur.¹⁸⁵

Positive effects are the reduced space requirement and the good extinguishing properties. A detailed examination was not feasible in the context of the preparation of the guideline, but the negative effects mentioned in the UBA study make it difficult to imagine that this technology could meet the C2C criteria. According to current knowledge, this type of extinguishing system is not to be used in C2C-inspired buildings, due to the toxic decomposition products and the associated negative environmental aspects.

Oxygen reduction systems: These systems represent a special case; here the reduction of the oxygen content is achieved by a permanent nitrogen supply, which already prevents the occurrence of a fire. These systems have a higher material and energy consumption than conventional inert gas plants. The energy consumption would not play a role in a 100% power supply from renewable sources, but the material consumption is important; such plants should therefore only be used where a particularly high protection of the material - eg irreplaceable cultural goods - is necessary.

184 Krimmling et al., 2014, p. 263

185 Pleß, 2003

11.3.4 Other usage-specific systems

Within the scope of this work, not all usage-specific and specialist systems can be dealt with; in the following, some initial information on these systems is provided.

Kitchen appliances and systems: A central question here would be the energy supply; from a C2C point of view, electric kitchens with a power supply from renewable energy sources would be preferable to gas kitchens. Another issue would be waste water treatment, which is in principle covered in chapter 3 “Water systems”.

Laundry or dry cleaning equipment: The main topics here would be energy consumption, water pollution and the use of chemicals; a power supply from regenerative energy sources must be ensured, and optimised laundering / dry cleaning processes must be selected in accordance with C2C criteria, and suitable water treatment systems must be provided (see chapter 3 “Water systems”).

Medical or laboratory systems: The central issue here would be energy consumption; the choice of system can, for example, reduce the need for ventilation. A further topic would be wastewater treatment, which is covered in principle in chapter 3 “Water systems”, but should also be simplified or supported by the system selection of the systems if necessary.

Stage lighting equipment: The main focus here would be energy consumption for stage lighting, which would have to be optimised in line with C2C; reference should be made here to chapter 8 “Electrical installations” and to chapter 12 “Building management / controls systems”.

Technical media supply systems: The main topic here will be how the media are produced in each case; eg efficient compressed air generation would have to be ensured.

Swimming pools: Apart from heat generation, water pollution will play a central role here; ozonation facilities should be chosen that pollute the water with as few chemicals as possible and, for example, and the rate of renovation of the pool water should be adapted to the actual water quality. Reference should be made to chapter 3 “Water systems” and chapter 5 “Heating systems”.

11.4 System design

As soon as the systems have been selected, the usual specifications of the system design as well as the design criteria defined under “Design criteria and boundary conditions” apply.

Sizing plays a special role in meeting the C2C criteria; it is here where material usage and energy consumption can be optimised.

In addition to the critical questioning of the design criteria (“which safety standard is necessary?”), an efficient design of the building layout has an influence on the number of fire-fighting facilities (eg need for fire-fighting systems to compensate for the lack of passive measures) and the use of materials (eg distance of the fire-fighting systems to the affected areas); here, the architect should be advised accordingly as early as possible in the corresponding process.

When sizing the pumps, it should be ensured that they have the minimum required size, to optimise energy and material consumption; the same applies to sprinkler tanks and pipes.

When designing the extinguishing systems, it should also be ensured that the systems and individual equipment can be repaired and dismantled. In this sense, it would be helpful to confront manufacturers with the C2C issue during the design phase (certification of elements and materials, list of materials used, design for disassembly) and to favour manufacturers making efforts in this area.

11.5 Material selection

As for the system selection, many aspects of material selection will already be specified in standards and regulations; this chapter therefore initially only describes the materials and deals with possible choices when possible. Where such choices exist, the material is to be optimised according to C2C criteria.

It would probably also help if MEP designers cooperated with manufacturers to review and pilot (even if only in a part of the installation) C2C-inspired products – this could lead to a rethinking and the development of new products, materials, or construction methods.

11.5.1 Piping systems

Metal pipes: Sprinkler pipes are usually made of either galvanised carbon steel (unalloyed steel) or stainless steel. For economic reasons, carbon steel systems are usually used which are VdS-certified and “FM approved”. These materials generally have good recyclability; however, this recycling is only possible through the use of fossil fuels.

From a C2C point of view, the pipes should not be painted unless the local code explicitly requests it; although the painting still allows the steel to be recycled, it becomes waste in the subsequent process. The paintwork itself is currently not yet recyclable and is mostly based on petroleum.

A generally valid indication as to whether acrylic varnish, synthetic resin or nitro varnish should be used is currently not possible; as an interim solution, where painting is required, paints with Type I sustainability labels such as the Blue Angel should be used. There is a first paint (Rustgrip from Superior Products International Inc.) which has only the C2C Material Health Certificate, but it is not yet available in any colours except grey (sprinkler pipes are usually painted red).

With ZINQ, there is already a company with C2C certification (Bronze) in galvanizing; this could be an option where the paint is applied for corrosion protection. Zinc has good recyclability; the low certification level is due to the low use of renewable energy in production – otherwise it could be higher.

Press or screw connection: In addition to screwed systems, there are also pipe systems with press connections (eg Viega). From a C2C point of view, the material properties are equivalent to screwed systems; however, pressing does not make facilitate a sorting of the material after disassembly, or a replacement of individual sections, which is a negative factor – screw connections are preferable in C2C-inspired buildings.

Flexible sprinkler hoses: Flexible sprinkler hoses are made of stainless steel. The flexible sprinkler tubes are connected to the rigid sprinkler tubes by means of a screw connection, allowing the system to be dismantled and the material separated. The system is therefore suitable for C2C-inspired buildings.

Connecting parts, couplings, reducers can also be made of steel and are either coated or galvanized. As there are no C2C coatings yet, but a *Cradle to Cradle Certified*TM galvanizing process (Voigt & Schweitzer GmbH, Bronze Level) already exists, galvanized components according to C2C criteria are preferable.

Plastic pipes: In addition to the most commonly used metal pipes, there are also special plastic pipes (eg from Aquaterm) which may be used for wet sprinkler systems. These pipes are composite pipes, consisting of two layers of PP-R and one fibre layer; due to the composite system, a qualitatively equivalent recycling according to C2C criteria is currently not possible, so they cannot be used in a C2C-inspired building.

11.5.2 Fixings

Further information on pipe fixings can be found in chapter 3 “Water systems” under 3.6.11 “Fixings (pipe clamps and mounting elements)”.

11.5.3 Fire protection shells

Hilti produces two *Cradle to Cradle Material Health Certified*TM fire protection sleeves (Firestop Cast-in Device CP 680-M/ -P/ -PX and CP 653 BA - Firestop Cast-In & Sleeve Device). The sleeves only have the Material Health certificate and achieved only Bronze level; however, it is to be supported that a company like Hilti strives to improve the material health of its components. Note, however, that these components are currently not available in all countries.

11.5.4 Fixtures

Installations such as headers, manometers, valves, vents and strainers must also be optimised according to C2C criteria. Due to the multitude of products and materials, it is not possible to examine all components in detail within the scope of this document and would have to be assessed in future work; it can only be said that at the time of writing there were no *Cradle to Cradle Certified*TM fixtures, or and produced to equivalent criteria.

11.5.5 Hand-held fire extinguishers

Hand-held fire extinguishers consist mainly of the container, the trigger mechanism and the extinguishing medium. The containers are made of metal, which in principle makes them recyclable; see 11.5.6 “Extinguishing agents” for further information on this subject. At the time of writing, there are no *Cradle to Cradle Certified*TM or similar portable fire extinguishers.

11.5.6 Extinguishing agents

Extinguishing gases: CO₂ is toxic and in an extinguishing concentration actually life-threatening; its use as an extinguishing gas is therefore not recommended in C2C-inspired buildings.

When selecting inert gases, nitrogen would be preferable to argon, as nitrogen is more abundant, and less energy is used in production; however, this is not an exclusion criterion for argon. Like nitrogen, argon is classified as harmless to the environment;¹⁸⁶ it is extracted from the air and is a by-product of nitrogen and oxygen production¹⁸⁷.

186 Institut für Arbeitsschutz der Deutschen Gesetzlichen Unfallversicherung, n.d.

187 Messer Group GmbH, n.d.

Due to the further process steps, argon production requires more energy than nitrogen production.

Chemical extinguishing gases such as HFC-227ea, HFC-23, Novec™ 1230 have no ozone depletion potential, but the same greenhouse potential as carbon dioxide. According to a UBA study, the use of these substances can also have other negative effects.¹⁸⁸ If the fire cannot be extinguished directly, corrosive and toxic decomposition products are produced during the extinguishing process, which are harmful to the person using them, and to the environment if released into the atmosphere. This means that the extinguishing agents were not designed for the usage scenario and therefore do not meet the C2C criteria.

Detailed comparisons of different extinguishing gases could not be found in the context of the research to this work; a more detailed examination should be carried out in follow-up work.

Extinguishing powder: Most portable fire extinguishers use ABC powder, which consists mainly of finely ground ammonium dihydrogen phosphate and ammonium sulphate. Both substances are also used as fertilizers or even as nutrients for microorganisms in sewage treatment plants; in principle, therefore, there is nothing to prevent their use in C2C-inspired buildings.

Extinguishing foam: There are fluorinated and non-fluorinated extinguishing foams. Fluorine-containing extinguishing foams contain polyfluorinated and perfluorinated chemicals which are very difficult or impossible to degrade in nature¹⁸⁹; this means that these foams are not suitable for C2C.

Non-fluorinated extinguishing foams can also have an impact on the environment and especially on bodies of water. In the research for this guideline, however, it was not possible to determine which fluorine-free extinguishing agents are more or less suitable for a C2C-inspired building.

For hand-held devices, some first environmentally friendly alternatives (Saclon 2 Eco, F-exx) are available on the market, which are biodegradable according to the manufacturer; however, the exact composition is not published, so that it is not possible in the context of this work to finally clarify whether these are more suitable for a use inspired by C2C.

11.5.7 Pumps

Pumps for extinguishing systems consist mainly of metal parts and seals; they are generally easy to dismantle and therefore recyclable.

At the time of writing, there are no *Cradle to Cradle Certified*™ or C2C oriented pumps.

11.5.8 Sprinkler heads

Sprinkler heads consist mainly of non-ferrous metal and a glass bulb filled with a special liquid; in principle, there is no choice here.

For architectural reasons, sprinkler heads are often chrome-plated or painted; from a C2C point of view, this should be avoided because of the reduction in recyclability.

Concealed sprinkler heads are initially not to be favoured for C2C-inspired buildings due to the higher material consumption.

11.5.9 Tanks

For water as extinguishing agent, information about tanks can be found in chapter 3 “Water systems” under 3.6 “Material selection”.

For gas as extinguishing agent, information about tanks can be found in chapter 4 “Gases and fuels” under 4.6 “Material selection”.

11.5.10 Hose reels

The enclosures for hose reels and dry / wet riser outlets are made of galvanised sheet steel or stainless steel; this means in principle good recyclability.

Where possible, C2C-inspired buildings should not be painted or powder-coated; where color coding is required, care should be taken to use paints that are as environmentally friendly as possible. At the time of writing, there are no *Cradle to Cradle Certified*TM or similar lacquers; acrylic lacquers with environmental certification (eg Blue Angel label) are preferable to synthetic resin lacquers.

The outlets are made of non-ferrous metal (brass); as a copper-zinc alloy, this has apparently good recyclability for both metals.¹⁹⁰ With the limitation of the high energy consumption, brass can therefore be regarded as suitable according to C2C criteria; the purity of the metallic constituents must be considered.

Hose reels are equipped with either flat hoses or dimensionally stable hoses. Flat hoses currently consist of polyester braiding and an internal rubber coating; the materials are inseparably connected to each other, so that recycling in accordance with C2C criteria is not possible. Dimensionally stable hoses are manufactured from EPDM plastics, some of which are multilayer; these also do not yet meet the C2C material criteria.

There are also no *Cradle to Cradle Certified*TM fire hoses yet. There is already a recycling structure for plastics; whether these C2C criteria can be met was not clarified during the preparation of the guideline. However, it can be assumed that some of the material can be recycled when using dimensionally stable fire hoses, so that this type of hose is currently preferred for C2C-inspired buildings.

At the time of writing, there are no *Cradle to Cradle Certified*TM or similar wall hydrants or dry / wet riser outlets.

11.6 Construction methods

Good accessibility and dismantlability must be ensured in the area of the extinguishing systems (see chapter 14 “Construction Methods”); casting or screeding in of pipes should be avoided as far as possible.

From a C2C point of view, tanks should be provided as separate components and not as an integral part of the building (eg watertight walls).

Pipe penetrations through walls must be done in such a way as to facilitate dismantling by type; direct plastering of the pipes must be avoided wherever possible.

Welding of fastenings should be avoided if possible; screw or clamp connections are preferred.

The distribution routes should be designed for the shortest possible paths.

12. Building management / controls systems

12.1 Aims and criteria

12.1.1 Overview

C2C aim	There are no 'own' aims for building management / controls systems - they only support the C2C aims of other systems (eg energy use, healthy indoor climate, material use, etc.)
C2C minimum criterion	Energy monitoring; employed materials and construction methods follow C2C criteria
C2C no-go criterion	Operation with electricity from fossil energy sources; use of materials on the "Banned List" of the C2CPII
C2C material criteria	See chapter 13
C2C construction methods	See chapter 14

12.1.2 Explanation

There are no separate C2C aims for building management and controls systems; the material and energy consumption of the system itself is relatively low, so that it only has a minimal impact on these aims. Nevertheless, these systems have a special role to play in achieving the C2C goals, because it is a prerequisite for achieving the aims of other disciplines:

- They control air supply, temperature and humidity, measure air quality, control lighting and shading, etc., making it critical to achieving the aims of a healthy indoor climate.
- The same applies to heat and electricity consumption - both are determined by building controls systems, and their compliance with C2C criteria are measured by these systems.
- They also control power generation and, in case of doubt, coordinate power consumption and power generation, being critical for achieving the aim of using self-generated renewable energy.
- By optimising energy consumption (and of course the cost of the system itself), building automation has an impact on the economy of the building.
- Building management systems contribute to a more efficient operation of equipment, leading to less wear and tear, which in turn reduces the need for replacement of parts and equipment, and thus the use of materials

- By using dashboards and other relevant tools building automation raises awareness and encourage building users to be more energy conscious, it also provides better tools for facilities management personnel to make better decisions in terms of energy and plant efficiency.
- Building automation can also be used to make the positive footprint of the building visible. Positive effects such as air filtration, positive energy self-sufficiency etc. should also be communicable to make C2C more widely known; they should also be analysable, to be able to further improve the positive effects in the next projects. Here, too, building automation plays a central role.

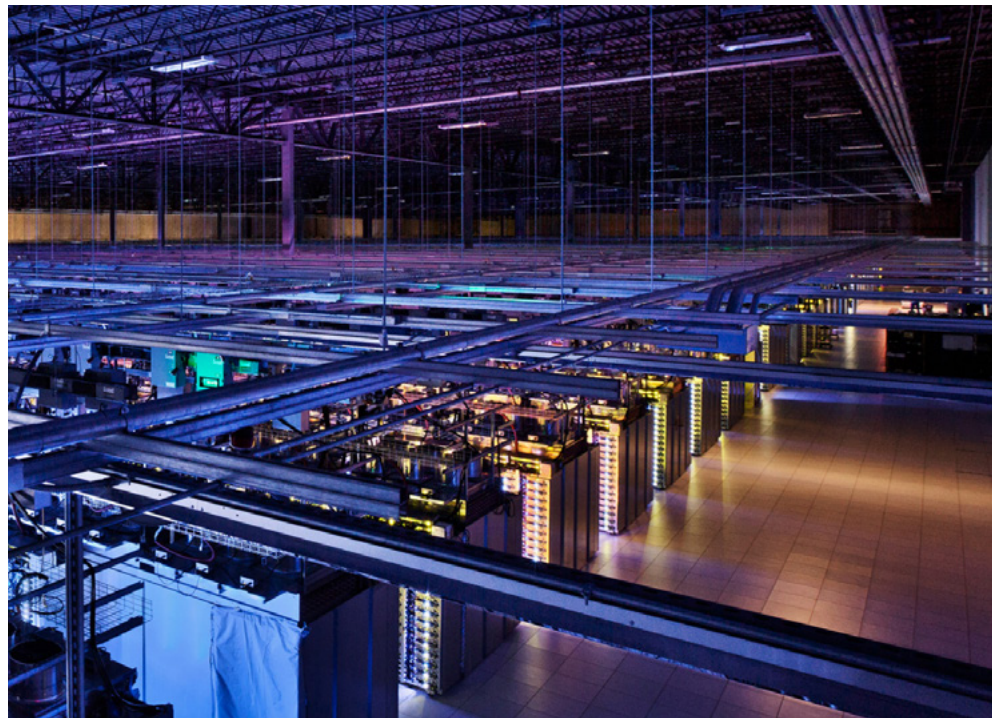
From a C2C point of view, this visualisation and support of the objectives of other disciplines is also the main function of building automation; objectives of optimising the use of materials in the system itself (eg reducing the number of sensors or cables) would have less priority than optimising performance or providing relevant data.

Nevertheless, from a C2C point of view, the components of building management systems are to be considered as products whose materiality should be optimised according to C2C criteria; this could for example include the material choice of casings for sensors.

The electricity supplying the building automation systems is already treated under chapter 8 “Electrical installations”; here there is an interdependency, because building automation should not only aim to operate and support other building areas effectively, but also to increase the use of self-generated renewable energy.

One of the C2C criteria for the built environment is monitoring the energy consumption of the building and its regenerative energy production; building automation must meet this criterion.

Image 28: Google Deepmind used machine learning to optimise energy consumption in their data center



12.2 Design criteria & boundary conditions

In principle, there are no specific design criteria; however, during the definition of the brief it should be critically questioned whether all systems are necessary, and the relevant C2C objectives like material use, optimisation of energy consumption and support of the C2C objectives of the other disciplines (eg increased use of self-generated renewable energy, improvement of air quality) should be listed.

C2C does not specify the degree of automation; the specifications in the chapters [12.3 “System selection”](#) and [12.4 “System sizing”](#) apply here.

During the establishment of the brief, it must still be stated how detailed the required energy monitoring is to be carried out. The C2C criteria do not state this specifically, but the monitoring should enable the user to optimise energy consumption and to match consumption and production.

At least

- central devices
- lighting / sockets
- main utilizations
- renewable energy sources

should be measured separately and stored in the shortest possible intervals (eg at least 10 minutes (electricity) or every hour (hot / chilled water flow, temperature, and energy consumption)) to evaluate and compare the individual daily and annual cycles and plot them against environmental parameters (eg outside air temperature and humidity).

It should also be indicated to which extent other values for compliance with the criteria of the other disciplines are to be measured or controlled; for example, air quality, water consumption and water quality are to be measured (in principle these measurements could also be carried out manually).

A further criterion of another MEP discipline is the possibility for the user to control the air quality / supply; during the establishment of the brief it is to be indicated to what extent and how this is to be ensured by the building automation.

12.3 System selection

Priority should be given to building automation systems that support compliance with the C2C objectives of the other disciplines as effectively as possible. The objectives are described in the individual chapters, and the optimisation of the systems is already sufficiently covered in other guidelines and not C2C-specific, so they are not covered here.

As there are currently no *Cradle to Cradle Certified*TM or C2C-inspired building automation components, effective material and energy use of the system itself is not possible yet. Consequently, the system should be selected for the lowest possible material and energy consumption of the devices (as few elements as possible, shortest possible cable routes) and overall durability – but without restricting the required functions of the system, and other quality criteria like mean time between failure (MTBF), etc.

An example of lower material consumption would be a structured cabling system, which can reduce the material use for cabling; another example would be combined sensors that reduce material consumption for casings.

A lot of material can be saved by ‘designing out’ systems:

An example would be the programming and regulation of lighting scenarios, which often are so complex that the users do not understand them and consequently do not use them; the use of simple switches would be favoured by C2C in this case.

Self-regulating systems such as volume flow limiters (instead of CAV boxes) or self-triggering fire dampers do not require integration into building automation and thus can save cables and controls.

A manually operated blind for glare protection does not require central control, but achieves the same aim as an electrically operated one.

Some measurements can also be carried out indirectly, eg by calculating the total consumption from the individual consumptions and not measuring them separately again.

The choice of systems should be evaluated in this sense, and building automation optimised accordingly – “less is more” often applies. C2C does not specify to what extent a building should be automated; however, a certain degree of automation will be necessary to meet the function of the building and the C2C objectives from other areas – however, automation should be operated “with a sense of proportion”.

The same applies to energy and quality monitoring – only enough technology should be used to achieve the objectives (optimisation of consumption, coordination of demand and production, quality control).

Whether centralised or decentralised systems are used is not decisive according to C2C – although this can influence the material input; where the systems have the same effect on compliance with the C2C objectives of other disciplines, the option with the lower material consumption (measured over the lifetime of the system) should be selected.

The same applies to site- or building-wide systems: A central building management system has a greater material input than autonomous, local control systems; in C2C-inspired buildings, it should only be used where it is necessary to achieve the C2C objectives of other disciplines.

How large the positive or negative influence of the building controls systems is, strongly depends on user behaviour; it should be kept in mind that trained users who are sensitive to C2C topics have a greater influence on energy savings in operation than building controls systems, and on the other hand, untrained users can completely cancel the positive effect of the controls systems.

In the design phase, this can be considered by systems that are as intuitive as possible to understand (an example would be so-called “hotel controls” for room systems that allow particularly simple and obvious operation); if necessary, an instruction of the users in the systems could be included in the tender documentation.

System selection could also consider the possibility of using reprocessed or re-use systems to reduce the negative environmental impact of the components; this could possibly influence the choice of manufacturer or system, again focusing initially on achieving the objectives of the other disciplines.

12.4 System sizing

Once the systems have been selected, the usual specifications of the system sizing, as well as the design criteria defined under “Design criteria and boundary conditions”, apply; here, too, the principle “less is more” applies – cable routes and the use of peripheral elements should be minimised wherever possible.

It is quite possible that the criteria for material selection have an influence on the system design; they must therefore be considered at an early stage.

It must be ensured that the measurements required in the other disciplines are covered by the building automation system; for example, the quality of the indoor climate and the waste water must be measured (the latter can also be monitored manually).

In addition to the required measurements, further values should be recorded if possible to measure, optimise and communicate the positive footprint of the building; this is not a must, but helps to check the positive effect and gain experience for next projects. Examples would be:

- Indoor and outdoor air quality; comparison of whether indoor air is constantly better than outdoor air
- Air quality outside and surroundings; measurement of whether buildings clean outside air
- Measuring the effect of biological filters or plants; important for future projects
- Rainwater and waste water quality; effect of water purification by buildings
- Determine solar coverage ratio; information on energy usage
- Quality of the indoor climate

Further design criteria relevant for C2C-inspired MEP are:

Flexibility: The systems must be flexible enough so that they do not have to be replaced in the event of future changes, but can be adapted or extended.

System interfaces: As open, expandable and universally applicable standards as possible should be used; this facilitates extensions and thus a better adaptation to newer technical developments (eg the use of apps for users to be able to monitor and control their local environment, dashboards and other tools)

C2C materiality: Even if no components yet comply with C2C criteria, manufacturers should be encouraged to start a C2C-inspired process by among others point out how this can enhance their overall market position and – depending on their suitability for the desired automation – those who are already taking the first steps in the right direction (eg origin of raw materials, material information stored (tag & track), uniform standard) should be supported. Further information can be found in chapter 13 “Material”.

12.5 Material selection

When selecting materials, the C2C criteria for materials are to be considered (see chapter 13 “Material”); this may also influence the system selection and system sizing and should therefore be looked at early in the design.

At the time of writing, there are no complete building automation systems or components that have been *Cradle to Cradle Certified*TM or manufactured according to C2C criteria. When selecting materials, manufacturers should be encouraged to apply C2C criteria, and components that at least make efforts towards C2C certification or material criteria should be given preference. Certificates of the Green IT movement such as TCO, Epeat, Energy Star, Blue Angel, EU Ecolabel can serve as a first orientation.¹⁹¹

The assessment of building controls according to C2C criteria is very difficult due to the technological complexity and the numerous electronic components, which can contain different rare earths and other materials that are not easily available. Although these materials are contained in very small quantities in the components, they cannot be separated from each other again, which would make the products unsuitable for C2C.

Material consumption should therefore be reduced by taking appropriate measures when selecting and designing the system; these will have a greater effect than the actual choice of material.

Some suggestions for the choice of material:

12.5.1 Reconditioned or reused components

A good way to reduce the negative effect of building automation is the use of “reconditioned” used components. Due to constant technical innovations, it will not be possible to use the entire system from used parts, but it should be checked which used components can be used if necessary. In the following paragraphs it is indicated where this may be possible.

12.5.2 Switch and server cabinets

Information on enclosures is already contained in chapter 8 “Electrical installations”; the indications given there apply accordingly to server enclosures.

12.5.3 Server (computer)

At the time of writing, there are no servers that have been certified or created according to C2C criteria.

For electronic components such as servers, there are currently few possibilities to use recyclable and fairly-produced technology. The use of materials should be as efficient as possible.

12.5.4 Peripheral devices (operating consoles, printers, modems etc.)

At the time of writing, there are no peripherals that have been certified or created according to C2C criteria.

Inkjet printers are preferred when selecting printers; laser printers emit fine dust particles that can be harmful to health.¹⁹² Even if the corresponding studies indicate that there is still a need for further research, the results to date can already be used as an argument not to use laser printers indoors. Although there are filters for laser printers that can reduce emissions, C2C does not consider this to be a viable solution – the negative effect is merely reduced and not resolved.

For many applications – also for printers – there is already a re-use market; since there are no C2C peripherals yet, it should be checked whether already used devices can be used, even if these devices do not yet correspond to the C2C concept.

Since March 2017, there has been a “Healthy Printing Alliance” in the printing sector, which aims to optimise printers and print products according to C2C criteria; however, at the time of writing the guideline, the project is still in its infancy and no concrete recommendations can yet be given.

For computer mice, there is the initiative of the “Fair Maus” from Nager-IT; the fabrication was as fair and recyclable as possible – all materials used and their evaluation according to fairness criteria are transparent and open source.

12.5.5 Data cable

Information on data cables can be found in chapter 9 “Extra-low voltage (ELV) systems” under 9.5.3 “Data cables”.

12.5.6 Cable trays, fixings

Information on cable trays, fastenings, etc. is already contained in chapter 8 “Electrical installations”; only specific installations of building automation will be dealt with here.

12.5.7 DDC automation stations

At the time of writing, there are no DDC stations that have been *Cradle to Cradle Certified*TM or created according to C2C criteria.

The overall concept of building automation must be designed to use as little material as possible (= central devices), but the operability and functionality should not be restricted – these have a greater influence on the C2C evaluation than the material of a DDC station. Modular DDC Stations, where the CPU and the I/O modules can be replaced / upgraded as necessary, can increase the overall life of the controllers and also improve the flexibility.

12.5.8 Input and output units (I/O modules)

At the time of writing, there are no I/O modules that have been *Cradle to Cradle Certified*TM or created according to C2C criteria.

12.5.9 Measuring and counting devices, probes, sensors

At the time of writing, sensors for temperature, CO₂, air quality, humidity, pressure, level, etc. are not yet *Cradle to Cradle Certified*TM or manufactured according to C2C criteria. One way to save material are multifunction sensors that use at least less material for the housings.

12.5.10 Control and regulating elements

At the time of writing, there are no actuators *Cradle to Cradle Certified*TM or manufactured according to C2C criteria.

The control and regulation elements – also called actuators – usually consist of electronic components, a housing (plastic or metal) and other components such as springs, sensors, motors, transformers, connection terminals, etc. Due to the large number of different actuators, there can be no statement made about the general materiality – this would have to be requested from the manufacturers on a project-specific basis.

12.5.11 Switch cabinets

Switch cabinets are already covered in chapter [8.6.7 “Switch cabinets”](#).

12.5.12 Operating units and touch panels

At the time of writing, there are no *Cradle to Cradle Certified*TM or C2C-inspired control units.

In the case of control units, an option is to specify them as tablets and buying them already used or from manufacturers who are already working towards sustainable production (eg Fairphone or Shiftphone). In addition, existing user components can be used for operating units, eg control via smartphones – no new operating units are required.

12.5.13 Cloud

IT services can be moved to the cloud to reduce material and component consumption. This may allow the data to be centrally processed by a data centre that is as energy-efficient and material-optimised as possible, rather than in a single small data centre for each building; it should be checked with the providers whether this is actually the case, ie whether their data centres are actually energy-efficient and have a high usage and/or utilisation rate. Topics like cybersecurity and data privacy will also play a role and can influence the system selection.

12.5.14 Controllers

At the time of writing, there are no controllers that are *Cradle to Cradle Certified*TM or C2C-inspired.

Controllers are electronic components that contain many materials; due to the large number of different controllers, no statement can be made here about the general materiality – this would have to be requested from the manufacturers on a project-specific basis.

Criteria for the selection of controllers to be in the spirit of the C2C concept could be modular construction, long planned lifecycle, long MTBFs, or upgradeability within a controller type.

12.6 Construction methods

The corresponding information in chapter ss applies accordingly.

According to C2C, (separable) plug connections are to be preferred to soldered connections for cable connections; they should be selected to be robust and have a long expected lifetime.

For later expandability, additional cable lengths should be provided for each data connection; the initially increased material costs are offset in the course of the life cycle by savings in the total replacement of the affected cable.

Flexibility in the space, ie sufficient space capacity in technical equipment rooms to accommodate future generations of equipment and infrastructures is also an important factor.

13. Material

13.1 Aims and criteria

13.1.1 Overview

C2C aim	100% C2C materials
C2C minimum criterion	Preparing a material passport for all systems
C2C no-go criterion	Materials from the “Banned List” of the PII

13.1.2 Explanation

The use of 100% C2C materials means that all materials used in the building are defined and are healthy for people and the environment in the corresponding usage scenario.

To comply with the principles of C2C, materials must meet the following criteria:

- The material must be recyclable
- The life cycle of the material must be described (including service life)
- The material must have been checked for harmlessness
- The material must be tagged
- It must be possible to separate the material components by material type
- The production process of the material must be carried out according to C2C criteria of social fairness, water quality and energy use.

In many cases, this will not be possible for the materials currently used in MEP and building construction; however, a minimum criterion would be that no materials are used that are on the “Banned List” of the Products Innovation Institute (PII), and that a material passport is maintained for all materials used in each system (not necessarily including product passports, though, as the information is currently mostly not available).

An interesting interpretation – especially helpful for MEP – is to see the building as a material bank, in which recyclable materials are stored (while it is also used for a function at the same time); at the end of their lifecycle, they are then dismantled and introduced to a new cycle. To facilitate this approach, during design and installation it must be ensured that the respective material is available again after use (individually retrievable).

It is also important to understand that materials produced according to C2C criteria can in principle be used indefinitely – if the criteria are met, no minimisation of the material consumption is necessary (although a minimisation of excess materials during construction is required).

A C2C certification is available for various materials and systems; certified products can – depending on the level of certification – safely be used in C2C-inspired buildings. Unfortunately, most certified products are currently for structures, façades and finishes and not for MEP, so this route is relatively limited.

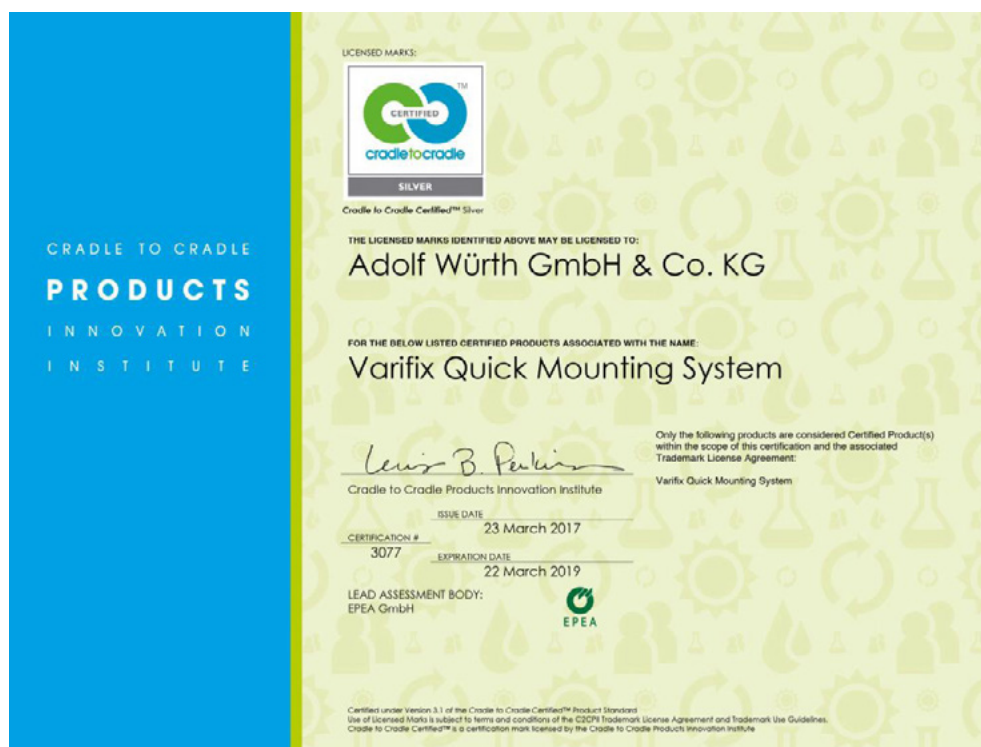


Image 29: Example of a *Cradle to Cradle Certified™* product certificate

This makes it more important to define generic objectives and minimum criteria for the use of materials in C2C-inspired buildings; whether these minimum criteria are achieved by means of a C2C certificate or another method is then irrelevant.

13.1.2.1 Banned list of the C2CPII

The Cradle to Cradle Products Innovation Institute (“C2CPII”; non-profit organization, www.c2ccertified.org) maintains a list of materials whose use is prohibited (banned) by environmental and health criteria in C2C-inspired buildings. This list is publicly available.¹⁹³

The fact that a material or product does not contain any banned ingredients is not necessarily evidence of the harmlessness of the material/product, but such banned lists are a good first point of reference for the current situation.

In addition to banned substances, there are also problematic substances that can be evaluated differently depending on the use scenario and application; unfortunately, the C2CPII does not currently provide a list of these substances.

13.1.2.2 Certified materials

In addition to the general C2C certification (with the categories water management, recyclability, renewable energy, social fairness and material health), the C2CPII also offers a Material Health certification (covering only the category material health). For this certification, ingredients are divided into a so-called ABC-X matrix; the letters stand for:

- A = optimal
- B = could be better
- C = tolerable
- X = problematic

Products can then achieve different levels of certification depending on their composition:

- basic
- bronze
- silver
- gold
- platinum

A product with a Gold Material Health certification does not contain any X-rated (problematic) substances; more detailed information can be found in the C2C certification framework of the C2CPII.

In addition to C2C certification of the C2CPII of materials, there are also other certifications for building materials (eg NaturePlus); a detailed comparison of the certifications is not included in the scope of this guide.

13.1.2.3 Aptness for circularity

The materials used in a C2C-inspired building should be reusable; this requires, for example, an aptness for disassembly and for a clean separation of the individual substances. For technical building systems, this means for example that the use of composite materials or bonding that inseparably binds materials should be avoided wherever possible.

A distinction is made between biological and technical cycles (detailed description in chapter [1.3.3 “The C2C cycles”](#)):

Biosphere - includes materials that are harmless and compostable, thereby enabling new organic growth at the end of their useful life as a biological nutrient base.¹⁹⁴

Technosphere - refers to defined materials such as metals or plastics, which are available in limited quantities as primary raw materials and are not directly biodegradable.

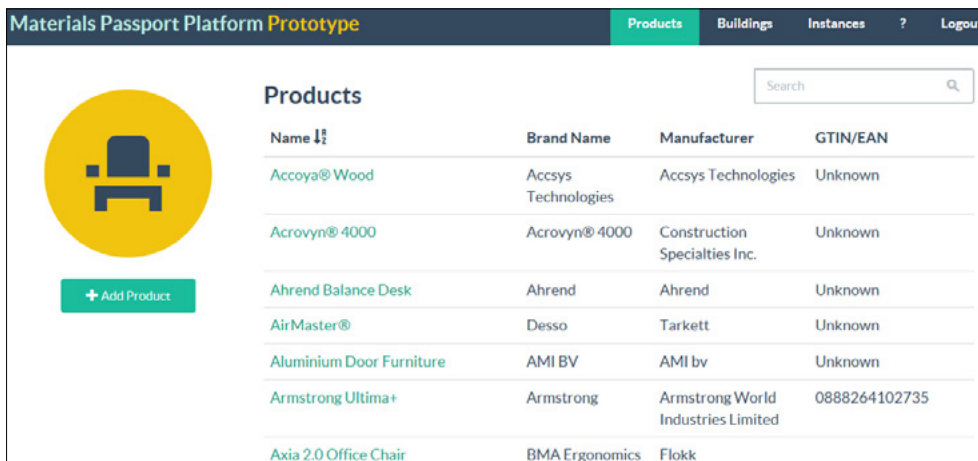
For all materials it must be determined whether they circulate in the technical or biological cycle; the complete lifecycle of the material must be described and the possibility of further use of equal quality must be demonstrated.

13.1.2.4 Material and product passports

If one follows the image of the material bank, material or product passports would be the savings books, so to speak; ideally, they document the complete material history, which includes extraction, processing, use, transformation, etc., as well as information on subsequent recycling. The objectives are to ensure compliance with the C2C criteria in the manufacturing of all materials in the building and to return the elements to their defined cycles in the event of dismantling.

So far, there are no uniform standards and regulations on material or equipment passports. As examples, the material passports of the EU project “Building as Material Banks”, EPEA “Circularity Passports” and the Madaster Platform can be mentioned here; these are currently only partially public, but basically all follow the structure described below.

The basic idea is to store all material and device-related information in a passport, which is then linked to the material or system; this can be in paper or electronic form, with the material itself carrying a reference number or RFID so that it can be matched with the data in the database.



The screenshot shows the 'Materials Passport Platform Prototype' interface. It features a dark blue header with navigation tabs for 'Products', 'Buildings', 'Instances', and 'Logout'. A search bar is located in the top right. On the left, there is a yellow circular icon of a chair and a '+ Add Product' button. The main content area is titled 'Products' and contains a table with the following data:

Name ↓	Brand Name	Manufacturer	GTIN/EAN
Accoya® Wood	Accsys Technologies	Accsys Technologies	Unknown
Acrovyn® 4000	Acrovyn® 4000	Construction Specialties Inc.	Unknown
Ahrend Balance Desk	Ahrend	Ahrend	Unknown
AirMaster®	Desso	Tarkett	Unknown
Aluminium Door Furniture	AMI BV	AMI bv	Unknown
Armstrong Ultima+	Armstrong	Armstrong World Industries Limited	0888264102735
Axia 2.0 Office Chair	BMA Ergonomics	Flokk	

Image 30: BAMB Material passport

At least the following data should be included in a material passport:

- Identification number of the material
- Composition of the material
- Quantity of material used
- Manufacturer / supplier of the material
- Material's cycle affiliation (biological / technological)
- Maintenance details
- Information on dismantling, recycling and separation by variety
- if applicable, certification of the material,
- if applicable, information on material health / harmfulness to humans

Where available, further information may be added:

- Origin: Information about extraction sites of raw materials, further processing to semi-finished products etc.
- Resource expenditure: recording and documentation of the expenditure of water and energy (also “grey” energy)
- Social responsibility: information about the supply and value chain, supplier conditions, etc.

Product passports would provide information on all materials used in the product or device, as well as information on the assembly and subsequent disassembly of elements or materials (construction plans), and if applicable on consumables like grease.

If necessary, it would make sense to structure the information according to systems, where the above information would be expanded to include information on the interaction of the individual elements and special features during their dismantling (eg systems under pressure or current, systems in which harmful substances can form in the course of operation, etc.) (see subchapter [14.1.2.2 “System passport”](#) in the chapter [14 “Construction Methods”](#)).

In the case of equipment, designers cannot be expected to compile complete information on all individual parts if they are not provided by the manufacturer; however, as a minimum requirement, the information should be requested from the manufacturers (who are currently struggling with this information).

13.1.2.5 Tagging

As described above, a material, device or system passport also includes a tagging of all materials or products, so that they can be associated with the information in the passport; this is crucial for further use or recycling.

This tagging can be implemented in several ways; there are projects with material identification using the known recycling numbers, RFID chips or QR codes; colour coding is also possible.

When using a tagging system, it is important that

- all individual products installed in the building can be clearly assigned to the material information in the passport,
- the markings are readable and searchable, and
- they are sufficiently durable to still be legible at the end of the lifecycle of the materials.

In the case of MEP installations, the tagging can be carried out in different ways. Many devices will have a tag anyway, which can also be used for the device passport. Individual materials will also already have recycling numbers that can be used for identification; other materials will have a colour code that – as long as it is unique – can also be used.

A special case are pipes and cables; it is not sufficient to identify them only once at the connection to the equipment they feed – the tagging needs to consider how the dismantling of the installation will be carried out, during which the materials must be identifiable at every point of the building. If necessary, the referencing is to be repeated room by room, and to be attached in a clearly visible place.

Currently, research is being carried out to optimise this important process; digital tools

- both to read the tags and to combine different tagging types in a common database
- will foreseeably play an important role in this area.

13.2 Design criteria & boundary conditions

The boundary conditions of the prohibition of materials from the “Banned List” of the C2CPII and of the preparation of a material passport are to be listed during the establishment of the brief.

It would also be desirable to define the planned degree of achievement of the C2C aim, but this is likely to be difficult because in many cases there is a lack of information on materials used in MEP equipment, there are few certified products, and the choice of materials can have a noticeable impact on the economics of the project.

It would make sense to lay down rules for the selection of materials in the brief; suitable rules would, for example, include

- Selection of certified materials where possible
- Mono-material is to be preferred over composite material
- In case of equal suitability, biological material is preferable to technical material.
- Health / wellness aspects have priority over energy performance

The envisaged implementation of the material passport, whether with the aid of Building Information Modelling (BIM) or other platforms, should also be outlined during the establishment of the brief.

13.3 Material selection

When selecting materials, the rules established in the brief are to be applied; the suitability of possible materials for the various installations are listed in the individual chapters.

It should also be checked whether second-hand (“pre-loved”) devices can be used, and whether the selected systems are reusable.

13.3.1 Choice of design

The criteria for the installation of the materials must also be kept in mind when selecting specific products, as the way products are assembled or connected on site can vary and be more or less suitable for a C2C-inspired building. These criteria correspond to the “Design for Disassembly” principle, which is described in chapter 14 “Construction Methods”.

13.3.2 Documentation

The material information for each system element is to be documented in the form of a material passport and transferred to a building or system passport; this is to be considered in the tender design (eg by providing a template), but likely only to be executed during / at the end of construction, when the final material choices have been made.

13.3.3 Tender

For a successful implementation of the C2C criteria, a description of the concept and the rules to be observed in the tender is fundamental; this also includes the continuation of the system or building passport.

14. Construction Methods

14.1 Aims and criteria

14.1.1 Overview

C2C aim	100% recyclability
C2C minimum criterion	Application of the “Design for Disassembly” principles
C2C no-go criterion	Connections of elements that do not allow a separation of materials by material type

14.1.2 Explanation

Even if the materials used in the construction are selected according to C2C criteria, this only covers a part of the material cycle required by the C2C concept; in addition, the materials are also to be joined to form system components or assemblies in such a way that at the end of their useful life it is possible to separate them by material type without reducing the material quality – the re-introduction of the respective material into the Bio- or Technosphere is not to be infringed, otherwise waste is produced and the long-term value of the material is reduced.

There are different levels of connection: Materials are connected to form components, several components to form assemblies, and several assemblies to form so-called exchange clusters¹⁹⁵, although the boundaries between the levels can be blurred.

An example:

Material: eg metal, plastic, lacquer
 Component: eg screws, housing, rotor, seal, cable
 Sub-assembly: eg pump, motor, drive
 Exchange cluster: eg pump group

The criteria for C2C construction must be met for all connections of the various levels; this means that separable connections must be used, and possibly influence choice of materials and detailing. Non-separable connections are only C2C-compliant if the connecting material is of the same material as the components to be connected (so that the purity of the variety is maintained), or if all components of the compound are optimised for the biosphere.

When selecting components, it should be investigated if inseparable connections are used in their fabrication or assembly; where possible, products with inseparable connections should be avoided. An example would be composite plastic pipes, which can no longer be separated according to type and are therefore to be avoided in C2C-inspired buildings.

During construction, separable connections are to be preferred over non-separable one; for example, adhesive gluing with materials of other types or chemical bonding (eg bonding of insulation to pipes or air ducts) must be avoided if this prevents separation by material type.

The use of a building component does not necessarily end with the end of the building's service life; for MEP systems, significantly shorter useful lifetimes are common than for the building itself, and it is also possible that components may have to be replaced in the event of equipment failures.

For this reason, preference should be given to construction methods that allow the replacement of wearing parts and do not require a complete replacement of the entire assembly if one component fails. The installation of the individual components or assemblies must also be designed in such a way that the parts can be replaced as far as possible without dismantling other parts; this would, for example, not allow components to be cast in concrete in C2C-inspired buildings.

14.1.2.1 Design for Disassembly (DfD)

The DfD principles are covered very well in the publication “Design for Disassembly: a guide to closed-loop design and building” of Pennsylvania State University (PSU)¹⁹⁶. The 10 basic principles of Design for Disassembly established there are:

1. Document materials and methods for deconstruction
2. Select materials using the precautionary principle
3. Design connections that are accessible
4. Minimise or eliminate chemical connections
5. Use bolted, screwed and nailed connections
6. Separate mechanical, electrical and plumbing (MEP) systems
7. Design for the worker and the separation process
8. Simplicity of structure and form
9. Interchangeability
10. Safe deconstruction

These basic principles must be considered during the design phase, the construction, and during refurbishments of the building.

14.1.2.2 System passport

In addition to the material pass presented in chapter 13.1.2.4 “Material and product passports”, information on components, assemblies or exchange clusters must also be collected and stored; this can be achieved by means of a system passes, which deals specifically with the construction method (see categories below) and allows all participants an overview even during the operation of the building.

A system passport can contain data from the following categories (taken and simplified from¹⁹⁷):

- Documentation: Used materials, connections and documentation of a de-construction plan.
- Selection: High quality, low CO₂ footprint, recyclable materials
- Access: Transparent construction, visible and accessible connections
- Minimize chemical connections: Avoidance of chemical compounds, binders, sealers and glues.
- Mechanical connections: Standardised connections, bolted, screwed and nailed connections.
- Separate building services: access to building services and disentanglement of different systems
- Human dimension: The interchangeability of individual components should be possible without heavy equipment.
- Simplicity: Simple floor plans, clear grids, regular dimensions
- Interchangeability: Modular structures
- Security: Safe and easy access to individual system components

Figure 15 below shows an overview of the most common component connections and an evaluation of their solubility.

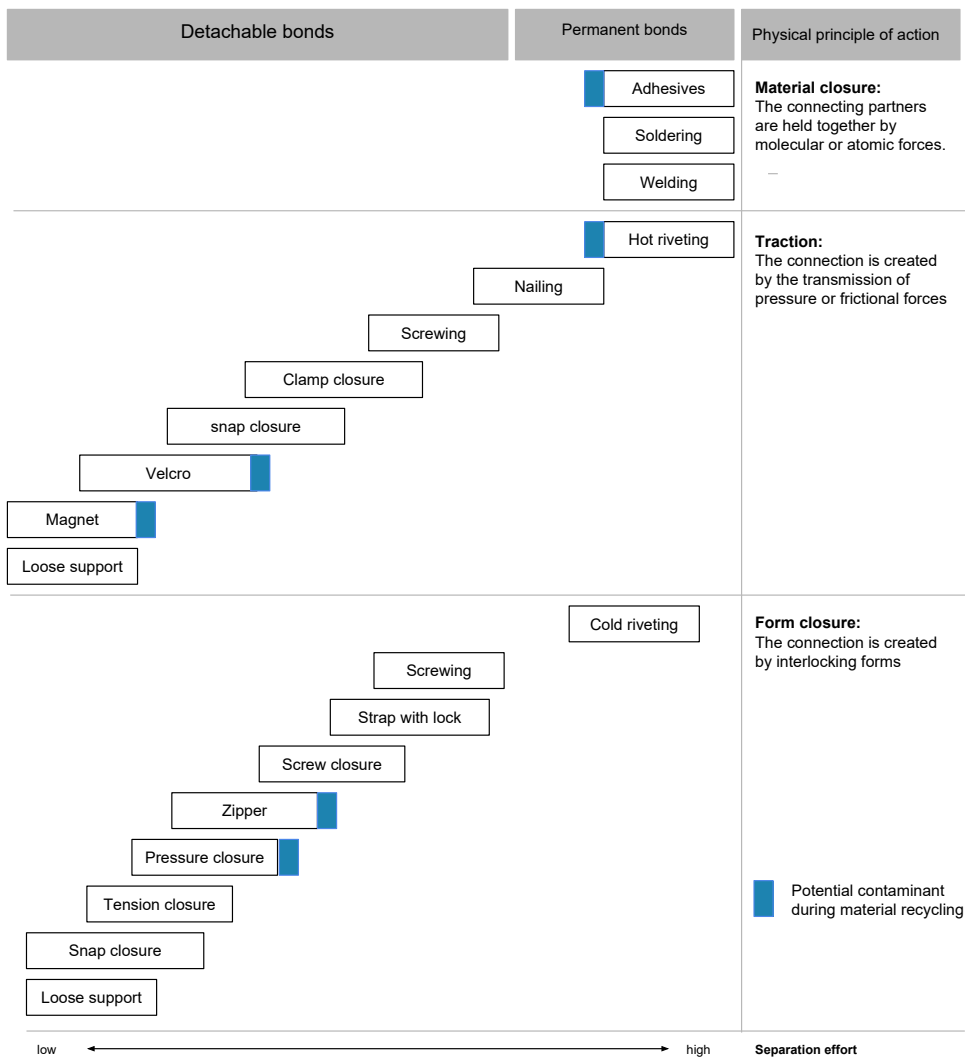


Figure 15: Overview types of connections, based on Brenner, Recyclinggerechtes Konstruieren, 2010, p. 58, translated and edited

According to C2C, soluble compounds are preferable to permanent compounds. The decisive factor, however, is whether additional substances are required for the joint, such as adhesives; this would also have to meet C2C criteria: In the case of a permanent compound with an additive, for example, all components would have to be optimized for the biosphere, or the additive would have to consist of the same pure material as the components optimized for the Technosphere.

In practice, permanent connections such as gluing can enable long-term use of the components. If there is still no alternative to this type of connection, care must be taken to ensure that the entire component, building component or exchange cluster can circulate at the same level of use, i.e. that it can be overhauled after removal and then returned to its intended use.

14.2 Design criteria & boundary conditions

The boundary conditions of the prohibition of component connections, which do not permit a separation by type, and the requirement for an application of the “Design for Disassembly” basic principles are to be specified during the establishment of the brief; here a referencing of the DfD basic principles is preferable.

14.3 System selection

The system selection will have a rather limited influence on the separation by type; certain technologies (eg photovoltaics) require the use of components that do not permit separation by type, which must be considered in the system selection.

14.4 System design

When designing the system, three aspects play a major role in ensuring separation by type:

- The selection of assemblies that can be separated by type,
- the selection of the connection types of the components or assemblies, and
- the detailing of the installation.

At present, it will not yet be possible to find manufacturers for all assemblies who manufacture their products according to C2C criteria; the issue must be addressed in the selection of components to the manufacturers to promote further dissemination of the C2C concept and further developments in this area. Where products are already available which allow or simplify separation by type, these should be given priority in the selection process.

The same applies to the types of connections; it will not always be possible to find alternatives to unresolvable connections, but this question should be addressed in each case, listing the types of connections chosen, assessing their C2C suitability and selecting the most appropriate ones.

When detailing the installation, the designers have the greatest influence (although this will partly contradict the desired aesthetics or space efficiency); in the planning, it should be ensured in each case that wear parts can be replaced without dismantling other elements (central planning, distribution; transport route concept, installation openings) and that all plant components are accessible (eg no covering in concrete; accessibility of shafts; inspection openings).

In this context, the “safe by design” concept should also be mentioned, in which the way in which components can be serviced or replaced during operation and the respective methods are to be described is considered in the planning - this would also be in the sense of C2C.

14.5 Tender

For a successful implementation of the C2C criteria, a description of the concept and the rules to be observed in the tender is fundamental; this includes in particular the DfD basic principles (in particular accessibility, avoidance of non-detachable connections and documentation), as well as the avoidance or reuse of surplus / waste.

List of abbreviations

AHU	Air handling unit
BAS	Building automation systems
BIM	Building Information Modelling
C2C	“Cradle to Cradle” – Book title with the meaning: From the Cradle to the Cradle
C2CPII	Cradle to Cradle Products Innovation Institute
CHP	Cogeneration of heat and power
DDC	Direct Digital Control
DfD	Design for disassembly
DGNB	Deutsche Gesellschaft für Nachhaltiges Bauen – German Sustainable Building Council
EPDM	Ethylene-propylene-diene rubber
EPEA	Environmental Protection Encouragement Agency
EVOH	Ethylene-vinyl alcohol copolymer
FBR	Fachvereinigung Betriebs- und Regenwassernutzung – Professional association for the use of operating water and rainwater
GRP	Glass fiber reinforced plastic
HFC	Fluorinated hydrocarbons
HNBR	Hydrogenated acrylonitrile butadiene rubber
HOAI	Honorarordnung für Architekten und Ingenieure – Fee structure for architects and engineers
IoT	Internet of Things
LCA	Life Cycle Assessment – Life Cycle Analysis
MBDC	McDonough Braungart Design Chemistry
MTBF	Mean time between failure
NBR	Nitrile Butadiene Rubber – Nitrile Rubber
ODA	Outdoor Air
PA	Polyamide
PE	Polyethylene
PE-X	Cross-linked polyethylene
PEMFC	Proton Exchange Membrane Fuel Cell
PII	Product Innovation Institute
PP	Polypropylene
PP-R	Random polypropylene copolymer
PSU	Power Supply Unit – PC power supply unit
PUR	polyurethanes
PVC	polyvinyl chloride
SBR	Sequencing batch reactor
SOFC	Solid oxide fuel cell
SML	Seamless pipe manufacturing process
UBA	Umweltbundesamt Deutschland – Federal Environment Agency Germany
UPS	Uninterruptible power supply
VOC	Volatile organic compounds
VOIP	Voice over IP – Telephoning over computer networks

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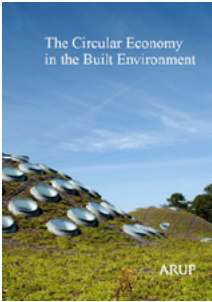
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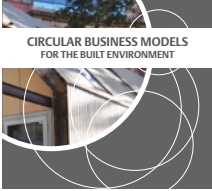
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This research jointly written by Arup and BAM explores ways Circular Business Models (CBMs) would provide added benefits throughout the value chain in construction.



Façade design for the circular economy

Shifting current thinking and design and fabrication practice to improve resource efficiency will be central to delivering a circular economy.

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