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A Pathway to Climate Neutral Buildings: Definitions, Policy and Stakeholder Understanding in Sweden and China

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Abstract. In recent years, ‘climate neutral buildings’ has become one of the most popular emerging terms in the context of global warming and the built environment. However, due to a vague definition, the term still lacks real-world uptake in practice. While initial research focuses on ‘climate neutral buildings’, few have discussed this term from the perspective of different countries or stakeholders. To address this gap, this paper explores the current understanding and future development of the term ‘climate neutral buildings’ in Sweden and China. Through a literature review of related definitions, an investigation of current regulations, and stakeholder interviews in both countries, we find that Sweden and China are in different stages of development towards climate neutral buildings. Sweden seems to surpass China in terms of theoretical research, regulation development and stakeholder understanding. Despite this, the two countries share similar issues regarding the future development of climate neutral buildings. Both countries lack an official interpretation of ‘climate neutral buildings’, sufficient regulations, and collaborations among different stakeholders. This paper suggests a foundation for the future development of climate neutral buildings.

Keywords: climate neutral building, comparative study

1. Introduction

Recent decades have witnessed increasing attention from many countries on the crisis of global warming [1]. Various climate targets have been set to reduce greenhouse gas (GHG) emissions and many technical terms have been introduced by numerous organisations and governments worldwide to help people understand climate targets. Recently, ‘climate neutrality’ has become one of the mainstream climate targets established by many countries and regions [2]. Responsible for a large share of energy consumption and GHG emissions, the architecture, engineering, and construction (AEC) industry has responded to this by introducing the concept of a ‘climate neutral building’. Although strategies exist in various countries to improve the development of the concept, there is limited use of the concept in practice. One reason is that the term ‘climate neutral building’ appears to be subject to different interpretations, and “climate neutrality” and “climate neutral building” still lack a unified and clear definition. These concepts are used by a wide range of actors and ultimately involve political questions



that cannot be defined easily [3]. They constantly attract debate, and contestation is therefore a key characteristic of these terms.

The same term can be interpreted differently under different social and environmental conditions as well as differently by individuals depending on their industry role. Many studies focusing on the term climate neutral building have been conducted, including the implication [4], the system [5], and related regulations [6]. However, few studies have discussed the term from the perspective of specific countries or stakeholders. As a prime example and a leading country in decarbonisation, Sweden regards achieving climate neutrality as one of the main goals of this century [7]. In contrast, China's absolute GHG emissions rank first in the world, accounting for about 30% of the world's GHG emissions [8]. Under these circumstances, China's pressure on reducing GHG emissions is significant. These two countries regard reducing climate impact as an important goal but under completely different national conditions.

To address this gap, this paper takes Sweden and China as comparative cases to discuss the definition of climate neutral building and policy development around the term as well as explore the understanding of climate neutral buildings from different stakeholders.

2. Method

Our methodological approach involved a literature and regulation review and stakeholder interviews.

2.1 Literature and regulation review

To define the concept 'climate neutral building', a literature review was conducted. Despite including similar terms such as "mitigating the greenhouse effect", only 34 scientific papers from the last 10 years world-wide were found after excluding the ones that do not provide a clear definition.

As regulations and policies can reflect a government's understanding of climate neutral building, the relevant public secondary sources for the international and national levels and for three cities in Sweden and four cities in China were reviewed. For Sweden, 12 reports and regulations covering the three categories of regulations that the AEC industry must follow in this country were reviewed: international regulations from the European Union (EU), national regulations from Boverket (Sweden's National Board of Housing, Building and Planning), and local municipal policies. For China, nine reports, regulations, and claims to understand China's approach to achieving its climate goals were reviewed: President Xi Jinping's statements at international and domestic conferences that are treated as China's general climate goals, regulations promulgated by the Ministry of Housing and Urban-Rural Development of the People's Republic of China that are treated as general policy, and laws and regulations issued by various local governments that are treated as local policy.

2.2 Stakeholder interviews

Since the term 'climate neutral building' is relatively new and has no unified definition, the opinions of relevant stakeholders (including people working in academia and industry) are also very important. A qualitative interview method is applied in this paper to get a perspective from the stakeholders in terms of and understanding of climate neutral buildings. Following previous research [9], we conducted a brief survey with semi-structured follow-up interviews with fifteen stakeholders from academia (e.g., professors, PhD candidates) and industry (e.g., architects, consultants) in China and Sweden to develop an understanding of the development stage as well as future potential success factors and challenges in academia and industry. The interviewees are listed in Appendix 1.

The participants first completed a 20-to-30-minute survey with seven questions focusing on definition and concept comparison, policies, and regulations, and influencing factors and development (Appendix 2). A follow-up interview of 20 minutes was initiated if the respondent's survey answers were not clear enough, in which the first author encouraged free flowing discussions with the interviewee.

3. Results

3.1 Definitions

In Table 1, we provide an overview of the definitions of the more general term, climate neutrality, we found through our literature review. In summary, although the definition of climate neutrality in different literature varies, the essence of all definitions is to have limited effect on climate.

Table 1. Definitions of climate neutrality from the literature review

Source	Definition
Intergovernmental Panel on Climate Change (IPCC)	A state in which human activities result in no net effect on the climate system. Achieving such a state would require balancing of residual emissions with emission (carbon dioxide)removal as well as accounting for regional or local biogeophysical effects of human activities that, for example, affect surface albedo or local climate. [10]
EU	A net-zero emissions balance through reducing GHG emissions as much as possible while compensating for any remaining emissions. [11]
Dhanda & Hartman (2011)	A three-step procedure: determine ‘the extent of carbon footprint’, ‘implement emission reduction’, and find ‘offsets for the remainder amount’ [12]

Turning from the more general term climate neutrality to the more specific one of climate neutral building, our review revealed that there were several other related concepts developed prior to the concept of climate neutral building.

- *Low energy building.*

The term ‘low energy building’ was first introduced in 1985 [13] and is viewed as one of the first examples of environmental-friendly architecture. While the definition of ‘low-energy building’ is diffuse, Thomas and Duffy [14] defined it as characterised by an energy-efficient design and technical features enabling high living standards and comfort with a low energy consumption.

- *(Nearly) Zero energy building (NZEB&ZEB).*

The US Department of Energy (DOE) defines a ZEB as “an energy-efficient building where, on a source energy basis, the actual annual delivered energy is less than or equal to the on-site renewable exported energy” [15]. The term first appeared around 1999 [16] and is still a trending term in the AEC industry.

- *Low carbon building (LCB).*

Low-carbon buildings are specifically engineered with GHG reduction in mind. By definition, a LCB building emits significantly less GHG than regular buildings. LCB is the first term to consider GHG emissions throughout the entire building life cycle and not only GHG emissions related to the energy consumption during the operational phase.

- *Carbon neutrality & carbon neutral building.*

Carbon neutral building is an emerging definition that relates to measuring, reducing, and offsetting carbon emitted by either a building or an organisation as a whole. There are numerous definitions and a summary of definitions can be found in [17]. One definition is a building with significantly reduced energy consumption combined with the increased use of low carbon energy sources to meet the remaining demand [18]. Carbon neutrality focuses only on carbon emissions while climate neutrality focuses on all possible impacts on the climate. Despite the difference, many authors do not deliberately distinguish between these two terms and even mix them as if they were the same.

- *Climate neutral building.*

Through our review, we found only one paper that specifically defined a climate neutral building. Rovers et al. [5] split ‘climate neutral building’ into three elements: the system addressed, the resource involved and the target itself. The resource ‘climate’ suggests that it also addresses the change in the use of the land as well as emissions from all greenhouse gases, not just carbon. The target aims at providing a balanced situation for demand/use and supply. ‘Neutral’ implies that the demand of energy or emission

production is always related to the system actions within and that the supply of resources can be inside or outside depending on the definition of the target.

3.2 Policy and regulations

3.2.1 Sweden. Sweden primarily follows EU regulations, followed by national regulations and local municipality regulations. *Goals and actions from different levels of regulations are summarised in [link](#).*

Sweden already has certain specifications for climate neutrality and climate neutral buildings. Sweden aims to achieve climate neutrality by 2045 in general [19][20], but several cities, including Stockholm [21], Malmö [22] and Gothenburg [23], plan to achieve this goal earlier on a local level. Local level regulations in Sweden also mention achieving climate neutrality in the AEC industry and the realisation of climate neutral buildings. In general, although not in any systematic framework, relatively detailed goals and initiatives already exist within current regulations for moving towards climate neutrality within the AEC industry in Sweden. It is worth noting that, however, that there is no clear definition of ‘climate neutral buildings’ in the related regulations.

In terms of action, two main actions mentioned most in international level regulations is to apply renewable forms of energy and promote more climate-friendly materials in buildings, and these specifications are further clarified on the national level with the promotion of energy efficiency in the building. The national regulations also take the impact of stakeholders into account on the completion of the goal. The local regulations do not only regulate the individual building, but also emphasize the participation of users and the products used in the building.

3.2.2 China. President Xi has given seven important speeches at international meetings regarding China’s main climate goal since the start of 2020, which is to strive to peak carbon dioxide emissions by 2030 and achieve carbon neutrality by 2060 [24]. In September 2021, the State Council promulgated the opinions on the complete, accurate and comprehensive implementation of the new development concept to achieve carbon peaking and carbon neutrality, and formulated actions at the national level [25]. According to the national action plan, the AEC industry should focus on three aspects to achieve China’s climate goal:

- Promote low carbon transformation of urban and rural areas, improve the level of urban greening, and strictly control the construction of public buildings with high energy consumption.
- Vigorously promote the energy-saving renovation of existing buildings and municipal infrastructure in cities and towns, improve the energy-saving and low-carbon level of buildings, comprehensively promote green and low-carbon building materials, and promote the recycling of building materials.
- Accelerate the optimisation of building energy structure, deepen the application of renewable energy in buildings, accelerate the electrification and low carbonization of building energy, and carry out building rooftop photovoltaic actions.

Various local governments such as Chongqing, Shanghai, Beijing, and Guangdong also respond to the call positively by stating declarations to help the central government achieve the planned goals. Since the central government of China only set the goal very recently, local governments did not have time to issue new regulations, yet. However, the published regulations related to green building, NZEB, and ZEB can also continue to be used as an instruction on the pathway to climate neutrality in the AEC industry. According to [26], three main actions in local regulations are the monetary subsidy, building’s plot ratio and the construction target.

3.2.3 GHG evaluation and limit value setting. How GHG emissions are calculated in regulations can also reflect a country’s views and initiatives on the pathway to climate neutrality. Table 2 summarises several important aspects in GHG calculation methods and setting of limit values in Sweden and China. Although some similarities in how GHG emissions are calculated in China and Sweden exist, many aspects differ. First, the technical term used to describe GHG is chosen differently. Sweden stated that it is GHG rather than only carbon dioxide in the calculation while China’s choice of words is carbon emissions.

In terms of calculation, China (Ministry of Housing and Urban-Rural Development of the People's Republic of China) and Sweden (Boverket) are both calculating based on the building life cycle. However, while the division of the full life cycle in Chinese regulations is relatively general and broad, it is more detailed in Sweden. In terms of building components, Sweden currently divides buildings into load-bearing structures, building envelope, and interior walls and it includes only these in the calculation. In 2027, installations, interior surface finishes and room fittings will also be added as components. In China, the building parts are roughly divided into building envelope and interior components for calculation.

When setting the limit value, both countries divide buildings into multiple categories and set the values respectively. Sweden divides buildings into single-family houses, multi-dwelling blocks, and non-residential premises, while China divides buildings into residential and public buildings. Sweden defines limit values to be complied within each module of the building life cycle, while China divides the specified limit values into two aspects: annual energy consumption including annual heating and cooling consumption and air tightness, and technical parameters including the U-value of the building envelope and the solar heat gain coefficient of windows.

Table 2. GHG calculation method and limit value setting in Sweden and China.

	Sweden	China
Climate impact calculation target	Greenhouse gas emissions	Carbon emissions
Life cycle modules to be declared	2022: Module A1-A5 2027: Modules A1-A5, B1-B7, C1-C4	Building operation, construction and demolition, and transportation stages
Building components	2022: Load-bearing structures, envelope, Interior walls 2027: Load-bearing structures, envelope, interior walls, installations, interior surface finishes, room fittings	Envelope (roof, exterior wall, floors, foundation) Interior components (floor, partition wall)
Building categories for limit value	Single-family houses Multi-dwelling blocks Non-residential premises	Residential building Public building
Limit value	Denote maximum allowable GHG emissions in each module	Annual energy consumption Technical parameters in different climate regions

3.2.4 Climate goals. In terms of the general goals, Sweden's target dates of climate neutrality are closer and more specific. It is worth noting that China has not mentioned climate neutrality in its declaration yet, and the current climate goal is still focused on achieving carbon neutrality. Despite this, the two countries still have similar acting directions in their policies. For instance, in the proposed future actions, they both emphasise the importance of new energy sources and materials; however, Sweden further applies this to architecture. When calculating GHG emissions, they both divide the life cycle into different modules, but China's division is broader. Due to the different situation regarding climate conditions and total area, Sweden's national regulations are relatively uniform while China's regulations vary from place to place. In terms of GHG calculation, China's overall limit value setting is broad, but it has more detailed regulations on different building components. Sweden does not specify building components but only the overall limit values for entire buildings.

3.3 Results from interviews

Although the sample size of the qualitative interview is not large, the results can still explain the insights and relevant experiences of stakeholders in China and Sweden on climate neutral buildings. Participants in academia hear the technical term ‘climate neutral buildings’ more frequently in their daily work than participants from industry. Most architects from China who work in the industry claimed they ‘never heard’ or ‘seldom heard’ the term climate neutral buildings, while participants from academia claim they ‘often come across it’ or ‘although not as frequent as carbon neutral, it is still often heard’. In the comparison of climate neutral buildings with other terms describing environment-friendly buildings, most respondents tend to believe that although climate neutral buildings share ‘similar goals’ with other types of environmentally friendly buildings, it is ‘more comprehensive’ and more focused on ‘a climate point of view’. However, more than one third of industry participants said they cannot see a distinction. When defining climate neutral buildings, academic respondents tend to use terms such as ‘negligible climate impact’, ‘zero in all types of emissions’, and ‘design follows the climate’ to make a definition. They also emphasise the importance of ensuring the building’s ‘liveability’ when trying to reduce the environmental impact of it while respondents from industry only emphasise the low climate impact. In terms of policies and regulations, almost all the respondents said that they ‘haven’t seen regulations on climate neutrality’. Some claimed that ‘carbon neutral regulations are more common’ and ‘currently regulations focusing on energy-saving are more often applied’. When asked about the future development and obstacles of climate neutral buildings in China, two thirds of respondents from academia and one half from industry believe that the government’s encouragement and policy guidance are the key factors in advancing climate neutral buildings.

Compared with China, participants from Swedish academia came across ‘climate neutral buildings’ in their daily work more frequently, and some scholars and architects even had experience in designing such buildings. Participants from industry also hear it on a similarly frequent basis. When comparing climate neutral buildings with other environmentally friendly buildings, respondents from both academia and industry tend to emphasise the outcomes, which is ‘zero in all types of emissions’ and ‘climate-related emissions’ although some of the participants from industry still focus on carbon emission only. Scholars also tend to emphasise the reference time, and they often view climate neutral building ‘from the perspective of entire life cycle’. These descriptions were also used when respondents were asked to define climate neutral buildings.

In terms of policies and regulations, although most interviewees said they had heard of relevant regulations and were aware of their existence, they did not know much about them. Many believed that the regulations can be ‘too many’ and ‘too complex’. Regarding future development and obstacles of climate neutral buildings in Sweden, respondents discussed a wider range of issues, including policy regulations, synergies, gaps between theory and practice, time, and economic development. According to the results, the lack of understanding of regulations and the cooperation of various stakeholders are the main issues Sweden face on its way to climate neutrality. Most participants think achieving climate neutrality goal in Sweden is feasible while still holding a critical point of view at the same time.

4. Discussion

4.1 Development of terms related to climate neutral building in Sweden and China

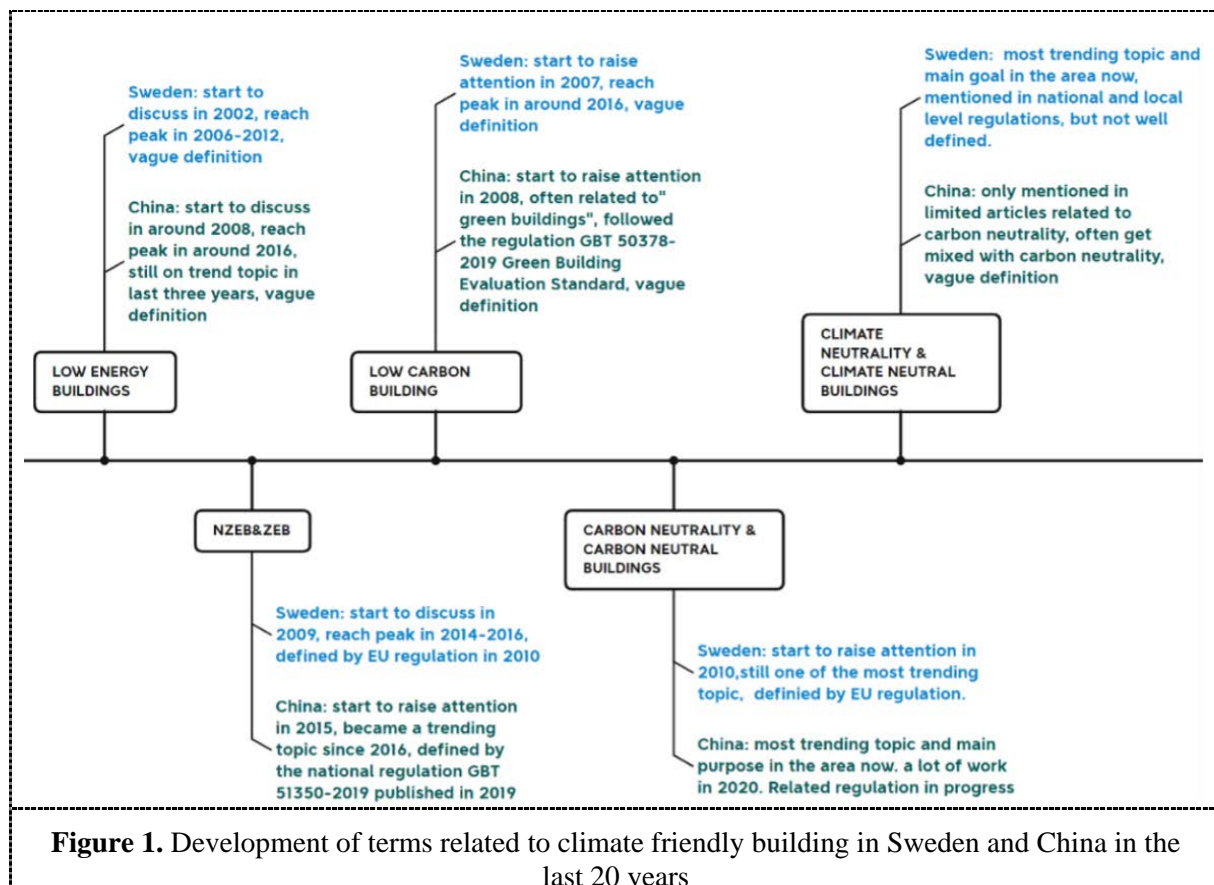
Figure 1 illustrates the path to achieving and understanding climate neutrality in Sweden and China. Sweden and China are currently at different stages in terms of theory development. Furthermore, Sweden has a relatively balanced number of research articles on LEB, NZEB, LCB and carbon neutral building. There are also several discussions on climate neutral building, indicating that Sweden has at least achieved a theoretical understanding of climate neutral building. However, most articles do not specifically target climate neutral building but instead discuss them as part of environmentally friendly buildings.

Most popular research directions in the current architectural academia in China include NZEB and carbon neutral buildings. However, the current discussion of climate neutral buildings in academic

circles is sparse, and there is no comprehensive definition. The term ‘climate neutral building’ only occasionally appears in articles and is often confused with the term ‘carbon neutral building’.

In general, Sweden is further advanced in terms of theoretical development as research on each technical term related to environmentally friendly building appears and peaks earlier than China. China has a larger number of articles, but this is not too surprising given the Sweden’s relatively small population compared to China. Sweden has already begun to discuss climate neutral buildings.

However, the number of articles is still limited, and there is no clear definition distinguishing it from other related terms. At present, China is still in the explorative stage of research on NZEB and at the starting point of research on carbon neutral buildings.



4.2 Sweden and China's current understanding of climate neutral building

Although a mature theoretical system is not yet developed, Sweden was one of the first countries to explore climate neutral building and already has a basic understanding of it. In related regulations, the term ‘climate neutrality’ is completely distinguishable from other related terms with its own complete system, including goals, initiatives, and frameworks. Although the term ‘climate neutral building’ is not specifically mentioned, the requirements for AEC industry under the climate neutrality target in the relevant regulations also allude to the understanding of climate neutral buildings in Swedish policies. However, not all related stakeholders have a clear understanding of this.

As for China, climate neutrality and climate neutral building have been mentioned in relevant theoretical studies in academia, even though there is no clear definition or understanding. However, related stakeholders especially the ones from industry could not distinguish climate neutral building well. China's current regulations also have not yet mentioned climate neutrality, and the most advanced climate goal is to achieve carbon neutrality, which the relevant departments began to focus on in 2020. In 2021, an expert panel was established to formulate relevant regulations. Therefore, it can be predicted

that China must first complete the understanding and discussion of carbon neutrality and carbon neutral building before trying to understand climate neutral buildings.

4.3 Future development of climate neutral building in Sweden and China

The literature review and the surveys show that although there still is no single unified definition of climate neutral building, different stakeholders in the Swedish AEC industry have a relatively consistent understanding of climate neutral buildings. Despite no EU regulations for climate neutral building, Sweden has already introduced many relevant national policies and provided economic support at the national and local levels. It can be speculated that the future development of climate neutral buildings has sufficient theoretical support, and the realisation of climate neutral buildings is already taking place in the industry. However, although policies are in place, the system is still confusing for most stakeholders. Cooperation among stakeholders in the practical process is also difficult to initiate. To achieve climate neutrality, Sweden needs the formulation of government policies, the help of the economy and the cooperation of all stakeholders.

China's primary goal at this stage is still achieving carbon neutrality. Interviewees from China generally considered that it is 'unrealistic and inappropriate' to require China to achieve climate neutrality within a short period. One of the interviewees noted that compared with European countries, China's land area is too large, and its economic development is relatively uneven. Under this scenario, it is inappropriate to ask China to keep pace with Europe and prematurely set climate neutrality as a goal. In addition, due to the lack of current regulations, it can be speculated that China will not be able to achieve climate neutrality in the near future. Despite this, the understanding of climate neutral buildings of most respondents from academia aligns with the common definition of climate neutral buildings in the world's academic circle. This means the development of climate neutral building on an academic level is still feasible in China, but it is impossible to make accurate predictions in the short term.

4.4 Limitations and future research

The selection of related terms in the literature review might not be sufficient as we might have missed other technical terms contributing to the understanding and development of climate neutral building. The terms included the most common ones according to the authors' knowledge and could be further extended in the future. The regulation review, especially the review of local regulations also could be extended to other cities and rural areas in each country. The total amount of survey participants was 15, and many of them were from the same city. As such, the survey is not statistically representative for either country. Nevertheless, it gives a first insight into the local situation. The survey could be extended in the future. Despite the limitations, this article sets an example of investigating the understanding of climate neutral building from combining a literature review, regulation review and stakeholder interviews. The results enable researchers to gain a better understanding of climate neutral building and current developments in Sweden and China.

5. Conclusion

'Climate neutrality' has become one of the mainstream climate targets established by many countries and regions. However, limited research discuss it from the perspective of the comparison of countries. This article takes Sweden and China as comparative studies to discuss 'climate neutral building' in terms of the definition, policy and stakeholders' understanding. In general, the results show that currently Sweden and China are in different stages of their development of climate neutral building. Much research related to climate neutral buildings was conducted in Sweden while the most trending research topic in China is still zero energy buildings and carbon neutral buildings. Stakeholders in Sweden generally have a better understanding of climate neutral building than stakeholders in China. Detailed regulations on various levels have already been issued in Sweden, and there are already climate neutral buildings being realised. Despite this, the two countries still share similar issues. Although most people have a consistent understanding of climate neutral buildings, there still lacks an official definition of climate neutral building to help stakeholders distinguish it from other terms such as zero energy or low

carbon buildings. Current regulations also lack a systematic framework in both countries. Regulations in Sweden can be too complex for people to understand while the regulation in China is vague and insufficient. The study demonstrates current issues for both countries and can be helpful for future development. Government's encouragement, policy guidance, and efficient collaboration of different stakeholders are the key factors in climate neutral building's future development in both countries. The overview of the current understanding and development in Sweden and China contributes to laying a groundwork for future research on defining similar terms and climate neutral building.

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Appendix 1: Information of participants in the interviews

	Country	Academia /Industry	Position	Years of working	Specialisation
A	China	Industry	Architect	3	Public building design
B	China	Industry	Architect	3	Public building design
C	China	Industry	Architect	4	Residential building design
D	China	Industry	Consultant	1	Green building techniques
E	China	Industry	Architect	4	Building design
F	China	Academia	Junior researcher	6	Bio-based building design
G	China	Academia	Associate professor	15	Sustainable buildings
H	China	Academia	PHD candidate	6	Building thermal engineering and energy saving
I	Sweden	Industry	Architect	2	Housing
J	Sweden	Industry	Consultant	2	Strategy consultant in sustainability
K	Sweden	Industry	Architect	3	Circularity
L	Sweden	Academia	PHD candidate	2	Sustainable buildings
M	Sweden	Academia	PHD candidate	3	Aerogel-based coating mortars for renovation of buildings
N	Sweden	Academia	PHD candidate	3	Heating system in buildings
O	Sweden	Academia	Professor	12	Role and fitness of the architectural profession for future challenges

Appendix 2: Survey questions

- Have you heard of "climate neutral building" or "climate neutrality" in your work? How often do you hear them?
- In your opinion, what's the most prominent difference between "climate neutral building" and other technical terms like 'low energy building', 'zero energy building', 'low carbon buildings', 'carbon neutral building'?
- Could you make a definition of "climate neutral building" based on your understanding?
- Are you familiar with the regulation related to climate neutral building in your country? How often do you use them in your work?
- What are your initial thoughts in relation to climate neutral building developments and what future do you see for this type of development in your country?
- What factors contribute or impede the implementing of climate neutral building developments in practice?
- In your opinion, what are the critical success factors for achieving the climate neutrality in ACE industry in your country?