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從低碳建築到零碳住宅 LowtoNo-以金門獨棟民宅為例

from low carbon building to no carbon house - LowtoNo

use of a single-family house in Kinmen as an example

科技部人文社會科學研究中心資助出版
The Research Institute for the Humanities and Social Sciences,
Ministry of Science and Technology be funded publication

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Chapter1 Foreword

由行政院環保署主導，計畫於 2014 年將金門打造成低碳示範島，縣政府也委外於 2011 年執行完畢低碳示範島規劃的上位計畫，雖然金門正處於以觀光立縣為施政理念的發展轉型階段，島上在這一片以低碳為議題的建設中，如何能真正兼顧觀光發展的「低碳經濟」應是整島發展首要目標，特別是島上有多項大型投資建設正進行中，因此如何利用理論兼具實務的節能減碳建設作為建築示範，是本書寫作之緣起，再就是作者本人也正在島上推動節能減碳宣導，利用興建個人住宅的同時，將低碳理念透過建築物興建，落實展現節能減碳建築手法，希望透過全程個人設計、監工及紀錄，同時比較個人早期於台灣以複合式外壁工法修繕完成的低碳住宅，作為說明低碳建築在台灣及金門因地制宜的不同，另外同時彰顯此幢建築藉由誘導式手法 - 再生能源、中灰水回收利用及建築外殼節能斷熱等，在金門逐年以碳補償、碳中和的方式達到碳足跡歸零的零碳住宅。

本書最後將以中英雙語的方式呈現發行，期使在金門小島的低碳到零碳理念也能宣導到國外。

Led by the Environmental Protection Administration, Executive Yuan, the Taiwan government is aiming to develop Kinmen Island as a low-carbon demonstration island. The first stage of the development plan for Kinmen to be established as a low-carbon demonstration island was completed in 2011 by outside experts engaged by the Kinmen County Government. Tourism is becoming the most important industry in Kinmen, and political policies focusing on this topic are also in a transition phase. Currently, most of the construction on the island considers the low-carbon aspect. How to take low carbon usage into account but balance the development of tourism is a primary objective of the island’s future plans. In particular, there are several major investments in construction projects that are in progress, and how to demonstrate to the public ways in which to apply the theories of energy-saving and carbon reduction to practical construction was the original concept of this book. In addition, I am also currently advocating energy conservation and carbon reduction on the island. One of my ways of achieving this task is to build my own home, employing low-carbon and energy-saving technology. In this way, through building a residential home, supervising the design and construction processes, and monitoring the energy and materials used myself, I hope to ensure the inclusion of carbon reduction techniques into the building. This project also examines buildings that employ composite construction and reinforced concrete methods in order to illustrate that the techniques used for low-carbon building construction require consideration of local conditions, including climate and geographic conditions. The current project also highlights the importance of using passive designs, including renewable energy, wastewater recycling (reclaimed water and greywater), and improving energy-saving by incorporating envelope insulation. Finally, I aim to achieve a zero-carbon house using carbon-offset and carbon-neutral methods.
This book is published in both Chinese and English in order that the concept of “From low-carbon to zero-carbon” can also be advocated overseas.

1.1 興建背景 Background

近年來極端氣候發生的頻率增加以及哥本哈根會議，已經改變世人對環境問題的態度，特別是氣候變遷導致地球暖化，溫室氣體減量已是二十一世紀全球共同關注之議題，其中又屬二氧化碳減量最為世人關注，然而大多數潛在的低成本溫室氣體排放量（碳）是隱藏在所謂建築環境中，因此低碳建築被許多人看作是一個關鍵途徑，提供大幅度削減二氧化碳的排放量，低碳建築便成為建築業界最主要發展的課題。台灣建築相關產業使用能源的二氧化碳總排放量，約佔全國總排放量的 28.8% [1]，以碳足跡來衡量建築物之興建，便占二氧化碳總排放量近 1/4，從建築行業的溫室氣體（GHG ）排放量已超過 1970 年以來，以加倍達到 9.18 $GtCO_2eq$，在 2010 年佔總排放量的 25 %，而非農業、林業和土地利用（AFOLU ）部門 (IPCC，2014) ，足見低碳建築之興建使用已成為先進國家建設發展重心所在。致於零碳生活之推廣，各國家大都止於低碳層面，尚未觸及零碳界面，本書最大特色是以低碳建築為平台，藉由搭配建築之低碳策略進行所謂低碳生活之規劃，也就是把建築減碳概念配合低碳生活發展至零碳層面，減碳範圍擴大至建築全生命週期，希望能達成所謂零碳生活終極目的。

In recent years, the increased frequency of extreme weather and the Copenhagen Summit have changed the attitude of the public towards environmental issues. In particular, climate change has a significant impact on global warming; therefore, reduction of greenhouse gas emissions has become a global concern in the 21st century, and reduction of carbon dioxide is an issue of concern worldwide. However, the majority of potential low-cost greenhouse gas emissions (carbon) are hidden in the building environment. Therefore, low-carbon building is seen as a key way in which to reduce carbon emissions, as it can substantially cut carbon dioxide emissions. Thus, low-carbon building construction has become the main aim in the development of architecture and the construction industry. In Taiwan, the total energy used by construction-related sectors represents 28.8% of the total carbon emissions nationwide [1]. According to the carbon footprint, building construction accounts for a quarter of the total CO_2 emissions. In terms of CO_2 emissions, direct and indirect emissions caused by construction, electricity usage and other energy usage for buildings account for about 21% of the national total carbon emissions, which is second only to industrial emissions. Greenhouse gas emissions from the building industry have more than doubled since 1970, reaching 9.18 $GtCO_2eq$ in 2010 (Figure 2.1), which accounts for 25% of the total emissions, not taking into account the agriculture, forestry and land use (AFOLU) sector. Construction of low-carbon buildings has therefore become a focal point in developed countries. In terms of the promotion of zero-carbon living, most countries adhere to a low-carbon national level, but few are focused on achieving a zero-carbon environment. The most important feature of this book is the use of low-carbon buildings as a basis and extending this to achieve zero-carbon buildings by introducing a low-carbon lifestyle that can further improve carbon reduction.

1.2 興建動機 Motivation

金門位處大陸東南沿海，資源匱乏，島嶼發展深受自然生態與人文環境的影響，1984 年從戰地政務轉型到發展觀光，此一重大轉折引入了大量觀光客，進而影響部份的生態 [2]。2004 年六月縣政府完成「金門永續發展策略規劃書」，以環境生態為基礎，提昇居民的生活品質為目標，以生物環境的承載量，作為經濟發展的限制條件，以共同解決環境生態問題，打造永續發展島嶼之理念。

為達到使金門成為節能減碳與永續經營的低碳示範島，配合在地特色及環境因子提出低碳建築生活零碳化可行性研究，構想希望透過金門低碳示範島上第一棟興建的低碳住宅，藉由整合基地之開挖到建築物興建後在各個建造階段的建築碳紀錄，完成興建過程建築物整體碳盤查總量計算，以實際運作說明如何以低碳策略中碳補償措施，達成逐步減碳效益，而成所謂之低碳建築，其中藉由低碳手法進行碳補償及碳中和達成零碳目的所須的年限，亦可經由計算得知，此乃針對建築物硬體之操作，然而實質居住的住家成員碳足跡累積則是成為整體零碳目標另一重要參數，也是本書所要探討主題之一。

The islands of Kinmen all lack fossil-fuel sources of energy, and the development of Kinmen is restricted by natural resources and the cultural environment. Since 1984, the transition from military administration to tourism has attracted a large number of visitors to the islands[2]; however, the development has also affected the balance of the established ecosystem. In June 2004, the Kinmen County government published the Strategic Plan for the Sustainable Development of Kinmen, which focuses on maintaining the ecology of the islands and improving the quality of life of their residents. The plan aims to limit economic development in Kinmen based on the biocapacity of the islands, and proposes application of the concept of mutual benefit in solving ecological problems and seeking to attain sustainable development.

In creating a low-carbon and sustainable demonstration island, consideration of local characteristics and environmental factors is a way of potentially turning low-carbon building into zero-carbon building. To demonstrate this, I undertook to build the first low-carbon building on the island to show the public how to achieve zero-carbon usage. With thorough examination of the design process from the beginning, the construction stages, and the management after the building had been established, the carbon usage at each stage was recorded and analyzed. In addition to the low-carbon design of the building itself, which can reduce carbon emissions, the use of methods of carbon compensation can further neutralize the carbon footprint generated during building construction. One goal of this book is to investigate how to draw up a well-designed carbon compensation plan for a low-carbon residential house that can then lead to the building becoming a zero-carbon construction after a certain number of years of usage. The other goal is to discuss methods of reducing the accumulative carbon footprint of a household.

1.3 興建目的
Aims

金門縣 2009 年溫室氣體年排放總量為 355,796 公噸，人均排放量為 3.79 公噸 / 人，分析溫室氣體來源，以能源部門之溫室氣體排放量最多，約占總排放量的 88.8%、其次為廢棄物部門占 7.8%、農林部門占 2.9%、工業製程部門 0.5%。進一步分析排放量最多的能源部門，其中以能源生產製造所占比例最高達 49.4%，交通部門次之約占 26.3%，若以電力消耗來看，住商部門排放量最高占 81.8% [3]。

由於建築物的溫室氣體是碳排放大宗來源之一，未來建築節能和減碳將成為建築界主流，「低碳建築」的理念不在於將建築時產生的碳排放降低，而是建築物在運作過程中藉由低碳措施的機能，用以抵消運作時因能耗產生的碳排放 [4]，這也就是低碳建築生命週期真正意涵。因此一棟低碳住宅建築興建，藉由低碳策略、碳補償手法的導入，達成低碳策略的目的，給予社會明確的說明，如何透過低碳策略，將低碳建築逐年走向零碳住宅，同時紀錄展現建築物內低碳生活，透過行為模式的調整，配合建築低碳策略，使得低碳建築到零碳生活，雖然目前很多國家如美國、德國、英國等已製定了自己的建築碳排放計量方法，但尚沒有一個國際上通行的公認標準 [5]。

The total greenhouse gas emissions in Kinmen County was 355,796 tons and the CO_2 emissions per capita was 3.79 tons in 2009. In terms of the sources of greenhouse gases, greenhouse gas emissions from the energy sector were highest, accounting for 88.8% of the total emissions, followed by the waste sector, which accounted for 7.8%, the agriculture and forestry sector, which accounted for 2.9%, and the manufacturing sector, which accounted for 0.5%. Further analysis of the highest CO_2 emissions in sub- sectors of the energy sector showed that energy production accounted for 49.4% and transportation for 26.3%. In terms of power consumption, residential and commercial usage accounted for 81.8% of the total power consumption, which represented the highest emissions[3].

As buildings are one of the major sources of carbon emissions, energy saving and carbon reduction will become mainstream principles in the construction industry. The principle of a low-carbon building is to minimize the carbon emissions during construction and integrate this with a self-generated renewable energy design to offset the carbon emissions and energy used during the operation of the building [4]. Therefore, construction of a low-carbon building can be achieved by the introduction of low- carbon techniques and carbon offset methods. The practical design offers the public a clear description of how, through a low-carbon strategy, a low-carbon house can reach the goal of zero-carbon housing. In addition, by monitoring lifestyle with regards to energy use, methods to improve energy efficiency can be identified, which can further help to achieve the target of zero-carbon living. Although many countries, such as the USA, Germany and the UK, have developed their own methods for the measurement of carbon emissions of buildings, there exists no international standard, though energy-saving and carbon reduction are widely accepted as important indicators globally[5].

綜觀一些主要的綠色建築評估系統已經將節能減排作為重要指標，可是它們仍然只關注建築運行過程中的個別直接能源消耗，評估有限的幾個能源消耗和碳排放項目，對其他能耗或碳排放項目則不做要求 [6]。

Some of the major green building rating systems have included energy-saving and carbon emission reduction as an important indicator, however, these systems still only evaluate items related to individual direct energy consumption during building construction, which measures some energy consumption and carbon emissions, but not all[6].

1.4 研究方法與範圍
Methods of the Study

有關本棟建築將以其興建過程作為研究的實務基礎，結合一些教學理論的探討，如建築物戶外部分有太陽能發電、風力發電、建築外殼保溫隔熱、複層式玻璃窗、太陽能熱水、植栽固碳及中水回收等，室內則有低耗能照明、太陽煙囱等領域之探討，這些設計手法及設備將轉換成減少碳足跡的補償方式，也就是降低建築物生命週期從搖籃到墳墓所產生的碳排放；另外將於第四章節透過國內本土性碳足跡之資料庫，以符合在地環境因子的計算方式，建立本棟建築之碳排紀錄，因此從建築生命週期整體碳盤查，亦就是從搖籃到墳墓概念，加上居住成員日常作息之碳足跡，實質呈現低碳建築到零碳生活完整的碳盤查紀錄 [7]，同時也符合本書作者原始想法，將研究理論付諸執行，就是在這施工二年期間就設計理念呈現在實務面及其中施作經驗，從建築物設計到監造獨自僱工購料方式興建完成，提供島上一棟可供百姓參考的示範建築，將心得以較平易的方式中英對照推廣給一般社會大眾，同時希望科技部資助的專書也能走入民間，將節能減碳的概念以深入淺出的方式，讓一般百姓也能透過本書在節能減碳共同理念下，就其經濟能力所及，以碳補償策略興建或改造自己的居家。

Using the construction of a single-family detached dwelling as a practical example, this study integrates theories and advanced technologies to design and build a low-carbon building. The designs include solar panels, wind turbines, building envelope insulation, multi-glazed windows, solar hot water, carbon sequestration by planting trees and wastewater recycling outdoors, and low-energy lighting and a solar chimney indoors. These technologies reduce the carbon footprint in order to compensate for the carbon footprint generated during building construction. Using a database established based on factors related to the local environment in order to calculate the carbon footprint, the overall carbon emissions of the low-carbon house designed by the author are calculated based on a life-cycle assessment approach. The entire life cycle of the building is considered, i.e., according to the concept of "from birth to death". In particular, the carbon footprint of the lifestyle of the building residents is taken into account, allowing the transfer from low-carbon to zero-carbon living to be fully recorded[7]. In addition, the author of this book aims to put theory into practice through this project. The dwelling can be used as a demonstration building for the general public, with whom the author can share their experience of the 2-year construction period, including information regarding design, construction supervision and purchasing of suitable materials. With the support of the Ministry of Science and Technology, who enabled publication of this book in both Chinese and English, the concepts of energy-saving and carbon reduction can be introduced to the general public in a simple way to demonstrate how easy these techniques are to apply in daily life. In this way, anyone who is interested and has the ability can participate in new low-carbon building construction or upgrade their home to a low-carbon dwelling by the method of carbon compensation.

1.5 核心精神
Significance

本書呈現從基地放樣開挖到建築物興建完成及最後成員入住，依據設計之低碳策略執行所謂碳補償，以中和基地開發不可避免的碳足跡，符合計畫之初三大研究核心精神 - 1) 低碳建築 2) 低碳生活 3) 建築生命週期碳盤查。

「低碳建築科技」如綠色能源與智慧綠建築不但是新興科技及知識，在金門低碳示範島的環境下，更應融入日常生活成為基本態度，低碳科技內涵包括綠色能源科技（如：風能、太陽能、海洋能、地熱能...等）、低碳生活（如：低碳交通工具、低碳觀光、綠建築...等），因此如何將綠色能源結合綠建築科技融入社區家園，特別兼顧在地氣候環境因子及地方習性，以適合金門發展低碳島之願景，其中特別是透過低碳建築以碳補償的方式結合生活，落實零碳生活之可行性。

This book presents the author’s building design, from groundbreaking to building operation after the household members move in. Although the carbon footprint generated during building construction is inevitable, carbon offset methods can be used to neutralize the carbon footprint during construction. The three major principles of this project are: 1) low-carbon building; 2) low-carbon living; and 3) life-cycle assessment.

"Low-carbon building technology" includes green energy and green building. It is not only an emerging technology, but should be integrated into daily life in Kinmen, as Kinmen has become a low-carbon demonstration island. Low-carbon technology covers green energy techniques (such as wind, solar, ocean energy and geothermal energy) and low-carbon living (such as low-carbon transportation, low-carbon tourism and green building). Integrating green energy and green building into residential housing, and also considering local environmental and climate factors as well as cultural habits, are the best ways in which to develop Kinmen into a low-carbon island. Using a combination of low-carbon housing and carbon offset is the key to achieving zero-carbon living.

1) 低碳建築

低碳建築是利用各種手段減少自身產生的污染，並將廢物合理利用，使用環保清潔的能源，以降低二氧化碳排放，最終朝向「零廢水」、「零能耗」、「零廢棄物」的理想狀態。低碳（零碳）建築的設計可能會比一般建築複雜，無論主動設計及被動設施皆需針對建築具體位置、使用要求和實際的能源使用情況來決定建築節能和再生能源的安排 [8]。

1) Low-carbon building

Low-carbon buildings are designed and constructed to reduce the generation of waste, recycle waste, and use clean energy to reduce carbon dioxide emissions, with the aim of zero wastewater, zero energy, and zero waste. The design of low-carbon or zero-carbon buildings is more complicated than that of conventional buildings. Active and passive designs both need to consider the building location, the operational requirements and the actual energy usage, in order to determine the strategy of energy saving during building construction and the installation of renewable energy sources[8].

2) 低碳生活

行政院於 2011 年核定金門為低碳示範島，島內從公務部門到百姓生活各項層面，希望皆能經由調適配合低碳建築之措施，以因應低碳生活，內容則著重資源循環、環境綠化、節約能源、低碳交通、低碳校園及低碳飲食等面向，以在地食材、有機農業、節能燈具、低碳運輸、低碳觀光甚至金門地區特有在地信仰的低碳廟會為主要內涵，透過本書宣導達成低碳生活之目標。

2) Low carbon living

Kinmen was designated a low-carbon demonstration island by Taiwan Executive Yuan in 2011. The government and the public sector hope to act in concert with low-carbon design principles to adopt a low-carbon lifestyle. Actions are focused on recycling, green environment, energy conservation, low-carbon transportation, a low-carbon campus and a low-carb diet. Practical activities include energy-saving lighting, promotion of the use of local ingredients, organic agriculture, energy-saving or green vehicles, and low-carbon tourism. In addition, local folk festivals and cultural activities are all encouraged to adopt the low-carbon concept.

3) 建築生命週期碳盤查

所謂建築物的生命週期 LC(Life Cycle) 就是建築物由出生到滅亡的時間，建築物的生命週期評估 LCA 就是由建材生產、營建運輸、建築使用到建築物拆解、廢棄物處理等過程的環境衝擊評估，亦即從建築物「搖籃到墳墓」進行全面性、系統性的環境衝擊評估。明確說法也就是從建築放樣開挖到建築興建完成及運作，包括居住成員之碳足跡紀錄，最終再以建築物約 60 年壽命計算其整體階段之生命週期，以達到從「搖籃到墳墓」之實質意義 [9]。

3) Life-cycle assessment

The life cycle of a building starts from the building construction, through the duration of usage, until its eventual demolition. Life-cycle assessment (LCA) evaluates the environmental impacts of a building, from building materials production, transportation, construction, operation or usage until demolition and the waste treatment process. It is an entire and systematic environmental impact assessment, i.e., "from birth to death" of the dwelling. More accurately, it is the carbon footprint record that covers the entire time from the breaking of the ground, through building construction, until construction is completed, as well as the time during usage when residents are living in the building and through the demolition process. This means that LCA of a building is conducted from cradle to grave, based on a general buildinglife cycle of 60 years [9].