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# The Study on the Carbon Reduction Measures Assessment of New Building Construction---Using Building Carbon Footprint Evaluation Method in Taiwan

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**Abstract**. The study used the BCF system developed by LCBA to calculate the carbon footprint of the building's life cycle. The case was the selection of a new educational building in Taipei, the first project in Taiwan to be required by government agencies to calculate carbon emissions. In addition to the calculation of carbon footprint, the purpose of this study is to assess the extent to which BCF tools can be used to feedback design contents before construction and to review the applicability of the tool itself. After BCFd's life cycle carbon footprint assessment, it can be seen that the carbon footprint ratio in the use phase is as high as 80.41%, followed by 7.76% in the engineering material manufacturing phase. However, in the design feedback of BCFd, although specific material selection suggestions are proposed, the application of regulations, maintenance, durability, etc., must be discussed. Based on the actual use requirements of the owner, this study proposes a correction plan for the material selection, and the BCFd method evaluation proves that it also has the effect of reducing carbon.

## 1. Introduction

In 2015, Taiwan's Legislative Yuan legislate a law named “Greenhouse Gases Reduction Control Act”, which stipulates that greenhouse gases emission must be reduced to 50% of 2005’s emission by 2050. Taiwan government has regulated certain highly polluting industries by impose fines or force shutdown if the registration of the number of carbon emissions is not honest. It can be seen that the mandatory carbon footprint management system has become an inevitable trend in Taiwan's industrial. However, in the past, without the carbon footprint calculation standard for buildings, there were many local governments that required carbon reduction in the review of the planning stage and the review of construction licenses, even local regulations also required provisions for investigation. In view of this, under the guidance of the Ministry of Science and Technology, the Low-Carbon Building Alliance(LCBA) was established in 2013, a certification system for building carbon footprints was established, and a low-carbon building industry platform was established to promote Taiwan's low carbon industry.

## 2. LCBA's BCD method

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The LCBA established a building-specific carbon inventory database in 2013 and invented a simple assessment tool to transparent Building Carbon Footprint (BCF). This is an analytical assessment that focuses on the "life cycle." The Lifecycle Assessment (LCA) is an environmental analysis tool that analyses the environmental impact of a product, service, or technical process from raw material acquisition, manufacturing processes, shipping, use, and final disposal. The construction industry project is like an ultra-large, long-life product, so it can examine its impact on the global environment from the life cycle perspective. Compared with general LCA, the BCF reflects the building's production characteristics by calculate the total carbon emissions of the building from amount of material in architectural drawing and database with a standardized life cycle scenario. The BCF can diagnose the hot spot of carbon emissions beforehand, and then achieve the effect of carbon reduction through design and material adjustment. According to the various stages of the life cycle, the evaluation scope of the BCF method is shown in Table 1. Moreover, BCF can be divided into four different tools by different timing for evaluation, there are BCFs - BCF Certification for Schematic Design, BCFd - BCF Certification for Design Development, BCFc - BCF Certification for Completed Projects and BCFo - BCF Certification for Occupant Buildings.

There are four core-principles built up the calculation and evaluation method designed by the BCF carbon footprint assessment system is based on and is designed to the calculation formula. The following are four principles.

• Compare by itself

The carbon footprint assessment method uses a carbon footprint as an indicator to assess the impact of a building on the environment. The essence of the assessment is that there must be objects of comparison. Therefore, in this tool, the design case is treated as a Benchmark Case and compared with the Baseline Case for carbon emissions. As a comparison object for improvement, the Benchmark Case is mostly set to the most basic and most common building by considerate the building type, basic conditions, market conditions and other factors. However, the Baseline Case and the Benchmark Case must be based on the same spatial function and the same building plan as the premise, then focus on evaluate the performance of the building’s facade, insulation, shading, structural system, durability, equipment energy efficiency, energy management and other factors, so that it can provide owners and designers a practical and controllable countermeasure.

• Compare by scenario

The BCF has the following main items for setting the standard situation: The first is the life cycle of the building, which is based on the foreign academic data and the results of the domestic expert questionnaire and then corrected to obtain the number of times the main materials need to be replaced. The secondary is the standard situation of engineering components. In order to simplify the process of evaluation, only the building’s main structure will be taking as the calculation object, and the small number of items in the project which won’t make any effort to carbon emission, such as pipelines, painting, engraving, small hardware will be deleted. The last one is to quote the energy consumption results of the long-term accumulation of buildings in Taiwan's academic circles, such as the average water consumption per person, etc., and standardize these data and apply them to the evaluation.

• Compare by influent factor

The carbon footprint assessment of a building can only operate, adjust, and control the carbon reduction factors related to building design and engineering, and cannot evaluate factors that are not related to the basic functions of aesthetics, taste, society, and economy.

• Compare by system

The BCF method does not calculate the carbon row for a piece of material, a pipeline, or an equipment component. Instead, it calculates the carbon footprint of a system based on the concept of a package, such as an interior compartment system, a curtain wall system and an air condition system, etc. In order to achieve an effective function of rapid evaluation, the BCF method simplifies a single system into a formulation, providing more effective time to improve carbon reduction hotspots.

## 3. Practical application of BCF method and carbon reduction design

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In 2015, with the implementation of the greenhouse gases reduction control law passed by the Taiwan's Legislative Yuan, the Ministry of Education accepted the recommendations of the Public Construction Commission of the Executive Yuan to conduct a trial of building carbon footprint assessment for new projects at all levels of schools as a lead. The first pilot case was the new construction of the Jin-Chin Building of the National Taipei University of Technology(NTUT). The building is a reinforced concrete structure with four floors underground and fourteen floors above ground. The floor area of the main building is 17860.46m$^2$. The functions of the building are divided into three types, the first is the indoor parking lot, the secondary is the restaurant for teachers and students, and the third is the general classroom and research room. The materials used for the exterior of the building is mainly close lightly pebble.

Since the Ministry of Education notified the Taipei University of Technology to request a carbon footprint assessment, the project has obtained a building license already, so the carbon footprint evaluating of the building was delivered to the research team by the general building contractor, then the results of the assessment were sent to LCBA to get certified. However, while the time of evaluation, the school has not yet decided on the main air conditioning system, it is in a state where the architectural design is completed but the equipment design has not yet been finalized. This study uses the BCFd system to predict the carbon emissions of the building and compare it with the Baseline Case to learn about the effectiveness of carbon reduction design measures.

At the design stage, the building has low-carbon design measures for equipment, durability, structural materials, interior finishing materials, exterior walls, flooring, and water equipment. The comparison between the benchmark case and baseline case are as Table 1.

**Table 1.** Low-carbon design measures

| Factors | Cases | Low-carbon design measures |
|---|---|---|
| Lighting & Air Conditioning | Baseline | • Using ordinary equipment. |
| | Benchmark | • All spaces using high efficiency lighting system.<br>• All spaces using independent air-conditioning with energy-saving stamps.<br>• All restaurants and laboratories have good natural ventilation conditions. |
| Durability | Baseline | • Using ordinary reinforced concrete as structural material.<br>• Ordinary general construction contractor. |
| | Benchmark | • Using high-spec reinforced concrete as structural material. (5000psi)<br>• The construction contractor was awarded the Excellent Quality Award by Public Construction Commission of the Executive Yuan within five years. |
| Structural Materials | Baseline | • Using ordinary reinforced concrete exterior walls with a thickness of 15 cm. |
| | Benchmark | • Adding blast-furnace slag and fly ash to concrete.<br>• The outer walls of some floors are 18 cm thick. |
| Interior Finishing | Baseline | • Using bricks as the partition and the surface is decorated with cement mortar. |
| | Benchmark | • 15 cm thick gypsum board partition wall for halls and most rooms. |
| Exterior Walls | Baseline | • The exterior walls are decorated with ceramic tiles. |
| | Benchmark | • The exterior walls are mainly decorated with close lightly pebble. |
| Flooring | Baseline | • Using ceramic tiles as flooring in the all interior spaces. |
| | Benchmark | • Using epoxy paint as flooring in the parking space.<br>• Using stone panels as flooring in the lobbies.<br>• Using raised floors(h=15cm) as flooring in the laboratories, classrooms.<br>• Using raised floors(h=30cm) as flooring in the equipment rooms.<br>• Using asphalt concrete as basement parking ramp. |
| Equipment | Baseline | • Using ordinary plumbing equipment. |
| | Benchmark | • Using Water Conservation Mark closets and faucets in the toilets.<br>• Using rain water utilizing system in the gardens.<br>• Rainwater storage tank in the raft foundation. |

The produced carbon emission of this case study, is the sum of the carbon emission from the five main phases of a building's life cycle. After converting the produced carbon emission into units of yearly emission per square meter, we can acquire the building's carbon footprint index, which resulted in the "benchmark case" and "baseline case" as such:

"benchmark case" life cycle's Total Carbon Footprint *TCF=CFm+CFc+CFeu+CFrm+CFdw-CFo = 9145985.075+7510873.503+94337515.071+5201125.605+1665273.892-0 = 117860773.147 (kgCO2e)*

"baseline case" life cycle's Total Carbon Footprint *TCF'=CFm'+CFc'+CFeu'+CFrm'+CFdw'-CFo' = 10882035.729+8804191.325+105917913.524+5136738.153+1849328.776-0 =132590207.507 (kgCO2e)*

*CFm ∶ Carbon Footprint of building materials (kgCO2e)*

*CFc ∶ Carbon Footprint of building construction (kgCO2e)*

*CFeu ∶ Carbon Footprint of energy usage (kgCO2e)*

*CFrm ∶ Carbon Footprint of repair/refurbish/renovate material life cycle (kgCO2e)*

*CFdw ∶ Carbon Footprint of demolition waste (kgCO2e)*

*CFo ∶ Other Carbon Footprints (kgCO2e)*

"benchmark case" Carbon Footprint Index:

$CFI = TCF \div AF \div LC = 117860773.147 \div 17860.46 \div 60 = 109.983\ (kgCO2e/(m^2.yr))$

"baseline case" Carbon Footprint Index:

$CFI' = TCF' \div AF \div LC = 132590207.507 \div 17860.46 \div 60 = 123.728\ (kgCO2e/(m^2.yr))$

*TCF: Total Carbon Footprint of a buildings life cycle (kgCO2e)*

*AF ∶ Gross floor area* $(m^2)$

*LC: Standard Life Cycle (yr)*

As seen below, the baseline case and benchmark case has reduced carbon emission by 11.109%.

Carbon Footprint Reduced percentage

*e CFR= (CFI-CFI')÷CFI' = (109.983-123.728)÷123.728 = -11.109%*

*CFI ∶ Building Design Carbon Footprint Index*

*CFI' ∶ Standard Building Carbon Footprint Index*

## 4. Life cycle's carbon footprint percentages

By assessing the carbon emission percentages of different phases from the Total Carbon Footprint, the emission from the five phases of life cycle are as follow: building materials (CFm) 7.76%, building construction (CFc) 6.37%, daily energy consumption (CFeu) 80.04%, repair/refurbishment materials (CFrm) 4.41%, demolition and waste disposal (CFdw) 1.41%. The highest percentage is from daily energy consumption, seconded by the amount of building materials used, with demolition and building construction taking a minimal ratio. (as Figure 1)

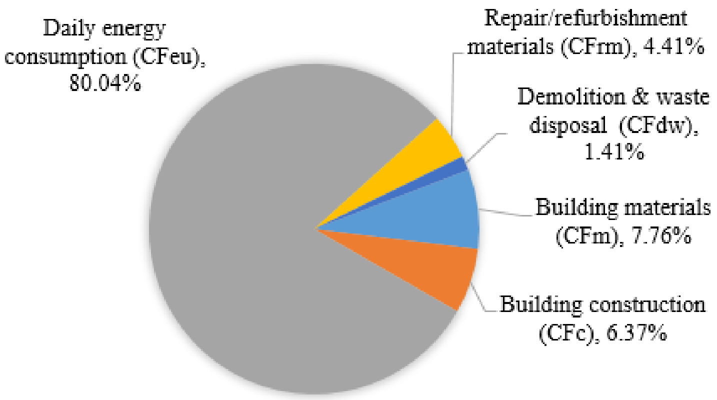


**Figure 1.** Carbon footprint from the five phases of life cycle

As Figure 2, The Carbon Footprint from daily energy consumptions includes: air-conditioning(CFa), lighting(CFl), electrical equipment (CFel), plumbing equipment (CFw), transportation (CFtr), heating equipment (CFg); these six facilities take up 27.11%, 20.44%, 19.16%, 0.67%, 0.87% and 31.75%. The heating equipment alone took up to 31.75% due to this building being partially a restaurant, and heating equipment requiring high energy consumption. The specifics for the heating system was not yet selected during the assessment at the time, therefore the settings in the calculation for the “benchmark case” and “baseline case” are the same. The “benchmark case” had air-conditioning with the energy saving label, and well-designed conditions for natural ventilation. High efficiency lights were selected for the lighting system.

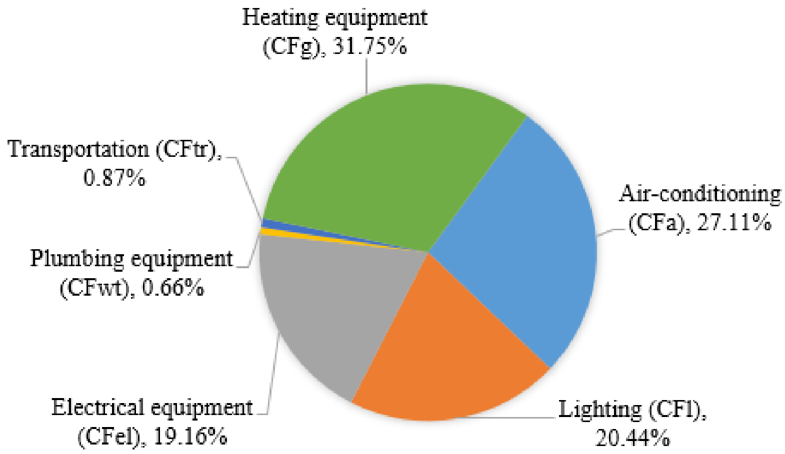


**Figure 2.** Carbon footprint from the daily energy consumptions

Escalating the scale of a structure or constructing earthquake resistant design in a building, will take up a larger ratio in energy consumption, resulting in more carbon emission. A commonly used method to reduce carbon is to lengthen the life cycle of a building by making it more durable. However, by lengthening the life cycle of a structure, the number of times other facilities are renewed will also increase, resulting in another form of carbon emission.

Facilities and roof materials are not allowed to be interchanged, because they involve basic function. For example, the pipe system will involve in fire protection; roofs need basic insulation and waterproofing, therefore neither should be considered as a changeable control factor. On the other hand, interior renovation differentiates depending on the resident, therefore difficult to keep track of, the finalized data could only use the data average from past case studies. Excluding these three, there are four categories left, exterior walls, windows, interior walls and floors. These four are often used as controllable targets for the BCFd method.

## 5. Improvement measures and potential for carbon reduction

By evaluating the specification and function of a building; and the results from the baseline case and benchmark case, the BCFd evaluation system will propose an “improvement plan” for choosing materials and the potential for betterment. The tool is specifically used for owners and architects to evaluate controlled data during the design phase, to achieve lower carbon emission for the project. It could be said that the BCFd is an environment-friendly aid design tool.

The suggested potential carbon reduced by the BCFd is listed 8 measures:

- Using gypsum boards(t=10cm) for staircases and equipment rooms to replace reinforced concrete walls(t=15cm).
- All toilets using rainwater utilizing system.
- Changing the existing 15 cm thick plasterboards to 10 cm.
- Using floor timber in the toilets, staircases, equipment rooms to replace ceramic tiles.

- Using cement mortar in the parking space and ramp to replace epoxy paint flooring.
- Using exposed concrete as cladding to replace composite aluminum plates
- Using floor timber in the laboratories、lobbies and equipment rooms to replace raised floors.
- Using exposed concrete as cladding to replace composite aluminum plates, close lightly pebble and ceramic tiles.

If all 8 measures are taken, 3.6% more carbon can be reduced. The design strategy is focused on the width and materials of partitions; recycled rainwater used in toilets; replaced flooring materials; simplifying outer cladding, etc.

However, after the discussion with NTUT maintenance department, architect and contractor, the feedback for the results of the BCFd had a few questionable points regarding material selection:

- On choosing partition walls, changing the reinforced-concrete walls to 10cm thick drywalls in fire regulated stair ways and areas will go against fire regulations.
- Most interior drywalls are designed to be 15cm thick, the recommended thickness is 10cm. The humidity in Taipei combined with the openness of the buildings design will cause the thinner slabs to deteriorate faster.
- The uncoated cement flooring in the maintenance room will have durability problems.
- The strength and slipperiness of using cement flooring in parking space and ramp would be weaker and more slippery.
- Regarding the lab and hallway, the baseline case uses raised flooring; the benchmark case uses wood flooring. Wooden flooring is not suitable for frequently accessed spaces by shoe wearers. The raised flooring on the other hand, is a system that can store cables and wiring, but the frequent changing partition in the lab conflicts with these raised flooring.
- The exposed concrete on the outer walls are uncoated, therefore susceptible to gradual concrete neutralization, and hard to maintain.

Based on the description from above, the case study (revised case) takes account for the regulation, durability and maintenance of partition, flooring and cladding; and propose a revised plan for choosing materials. The three categories (partition, flooring, cladding) are compared in cost and carbon footprint case by case: benchmark case (scenario A), improvement plan case (scenario B), revised case (scenario C). The carbon footprint data is from the LCBA database; unit prices of materials are based on the average construction material costs in 2018, published by official Taiwan statistics.

**Table 2**. Material use in three scenarios

| Part | Space | Area($m^2$) | Scenario A | Scenario B | Scenario C |
|---|---|---|---|---|---|
| Partition | Lobbies | 344.60 | Gypsum boards (t=10cm) | Gypsum boards (t=10cm) | Gypsum boards (t=10cm) |
| | Equipment rooms | 883.05 | Gypsum boards (t=10cm) | Gypsum boards (t=10cm) | Calcium silicate (t=10cm) |
| | Kitchen | 101.35 | Gypsum boards (t=15cm) | Gypsum boards (t=10cm) | Calcium silicate (t=10cm) |
| | Laboratories | 2189.99 | Gypsum boards (t=15cm) | Gypsum boards (t=10cm) | Gypsum boards (t=15cm) |
| Flooring | Equipment rooms | 269.45 | Epoxy paint (2mm) | Cement mortar | Epoxy paint (2mm) |
| | Equipment rooms | 110.32 | Raised floors | Floor timber | Raised floors |
| | Laboratories | 6523.47 | Raised floors | Floor timber | PVC flooring |
| | Parking & others | 7723.38 | Asphalt concrete | Cement mortar | Asphalt concrete |
| | Ramp | 590.09 | Epoxy paint (t=3mm) | Cement mortar | Epoxy paint (t=3mm) |
| Cladding | Walls Zone 1 | 598.70 | Aluminum plate | Exposed concrete | Ceramic tiles |
| | Walls Zone 2 | 4330.35 | Close lightly pebble | Exposed concrete | Ceramic tiles |
| | Walls Zone 3 | 2830.68 | Ceramic tiles | Exposed concrete | Ceramic tiles |

**Table 3.** Carbon emissions & prices per unit area of materials

| Part | Materials | Carbon emissions per unit area ($kgCO_2e/m^2$) | Material prices per unit area ($NTD/m^2$) |
|---|---|---|---|
| Partition | Gypsum boards(t=10cm) | 18.47 | 800 |
| | Gypsum boards(t=15cm) | 25.12 | 900 |
| | Calcium silicate(t=10cm) | 17.15 | 1200 |
| Flooring | Epoxy paint(2mm) | 21.05 | 430 |
| | Epoxy paint(t=3mm) | 29.50 | 550 |
| | Cement mortar | 13.58 | 389 |
| | Floor timber | 21.60 | 3050 |
| | Asphalt concrete | 73.39 | 343 |
| Cladding | Composite aluminum plate | 6.89 | 7500 |
| | Exposed concrete | 0.00 | 616 |
| | Ceramic tiles | 26.55 | 1768 |
| | Close lightly pebble | 15.98 | 1450 |

**Table 4.** Carbon emissions and price from three scenario simulations

| | Scenario A | | Scenario B | | Scenario C | |
|---|---|---|---|---|---|---|
| | Carbon emissions ($kgCO_2e$) | Price (NTD) | Carbon emissions ($kgCO_2e$) | Price (NTD) | Carbon emissions ($kgCO_2e$) | Price (NTD) |
| Partition | 80233.16 | 3044326 | 64995.75 | 2815192 | 78933.75 | 3427951 |
| Flooring | 114557.89 | 38350382 | 0.00 | 479993 | 206020.83 | 13719202 |
| Cladding | 1310289.10 | 26432443 | 284671.53 | 27009660 | 431931.42 | 11694334 |
| Total | 1505080.15 | 67827151 | 349667.28 | 59683907 | 716886.00 | 28841488 |

According to the above two tables, the carbon emissions of scenario C is between case A and scenario B. The reason for the high carbon emissions of scenario A is that the flooring is made of a large amount of raised flooring made of alloy steel and PVC. The lowest carbon emission of scenario B is using exposed concrete that does not need to be finishing on the wall surface. Among the three options, scenario A's cladding has the highest carbon emissions, due to the full use of ceramic tiles as the outer wall. If the material in the design phase is selected and scenario A is replaced by scenario C, then 788194.15 $kgCO_2e$ carbon emissions can be reduced.

As for the price, the total price of scenario A is the highest, because of the large amount of materials such as raised flooring, close lightly pebble and aluminium alloy wall panels. However, considering the maintenance in the future, these products only require less maintenance costs, so it is impossible to evaluate the advantages and disadvantages of the initial cost alone. On the other hand, the lowest total price is scenario C, because the expensive raised floor is replaced by cheaper PVC plastic tiles. Although this strategy can reduce the cost and can be adapted to the common compartment changes in the school. However, since various equipment wires cannot be hidden or stored, they may appear messy visually.

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## 6. Discussion and concluding comments

### *6.1 Discussion*

Global awareness for reducing carbon is on the rise. As so, the complexity of construction businesses not only need to consider a buildings cost and function, but also the controllable environment load factors that can reduce carbon. The goal of this case study, is to find the most cost-efficient way to reduce environment loading; between the current version and the advice from the idealistic carbon footprint evaluation system, regarding the suggestions of materials proposed by BCFd for this building design, this study proposes the following views.

1.Space Applications:

Spaces with different applications will result in various settings for reducing carbon. This case study focuses on three areas: parking space, educational research space and kitchen space.

• Parking space

Parking spaces lacks the need for air-conditioning, so to reduce daily energy consumption, choose high-efficient lightings. Regarding the pavement of the parking space, asphalt-concrete is easy to use and cost less, making it easy for maintenance. However, asphalt-concrete is susceptible to oil and emits more carbon, therefore it is better to use only on ramps to lower maintenance time; reducing the time for shutting down the whole parking area. As for the basement parking space including the car path, it is advised to use hard-coating. If wearing and slipping is of concern, emery and other harder materials can be applied to the outer surface.

• Education research space

Regarding the daily energy consumption in the education research space, separated air-conditioning system are recommended, because operating in each space separately is more energy efficient. Energy-saving labelled air-conditioners and well-designed ventilation are also recommended. Furthermore, it is recommended to choose high-efficient lightings to reduce carbon emissions.

It is common for schools to change partition every 5 to 10 years. Therefore, it is recommended to use dry construction methods, and fill the gaps between the partitions with filaments to make a sound barrier. Calcium silicate boards were used in this case for their reusability.

Internet and phone cables are routed from the ceiling or though the floor from the maintenance room to the research lab, the difference in practical requirements makes it hard to compare cost & carbon emissions. For example, if the cables are routed from the ceiling, the floors could use a cheaper and low carbon emitting PVC flooring, making it more convenient to change partitions in the future and more durable. If the cables go through from the floor however, a raised flooring will require alloy and aluminium, which is more expensive and emits more carbon.

• Kitchen space

This case has a special condition, being that it has not yet acquire investors, and so had not decide upon the partition, with the current partition following fire regulations and codes. It is suggested to use dry construction methods, for future investors to decide on the partition.

• Other spaces

The maintenance room is a specific space that needs to consider durability, reinforced concrete walls are recommended. For the flooring, a hard cover is basically preferred over from cemented flooring. The reason being that, although cement slabs can be trowelled, it will crack with no expansion joints, the worst scenario will cause dust. In special scenarios, like having lots of cables and wiring, raised flooring will be more manageable.

2.Choosing cladding material:

Choosing cladding material considers a buildings aesthetics, cost, maintenance, etc. The fair-faced concrete systems recommended in our country is not yet developed enough; the humidity in local areas make it hard to maintain the appearance of fair-faced concrete and pebble washed cladding. Accounting the cost, aluminium covers are far more expensive than other materials, second to it is ceramics tiles. Considering maintenance, fair-faced concrete and pebble washed cladding need regular cleaning; aluminium covers needs the filament to be regularly replaced; ceramic tiles have public safety concerns, after a long term tiles might drop, and inspections will require additional funds. The size of ceramic tiles will affect the dangerousness of dropping tiles, and since public building have more inspections than private ones, government projects can consider smaller sized tiles.

*6.2 Concluding comments*

The study used the BCFd method to evaluate the life cycle carbon footprint of an actual building project. In the analysis of this case, it can be seen that the carbon footprint ratio in the use phase is as high as 80.41%, followed by 7.76% in the engineering material manufacturing phase. For the carbon reduction measures, the study also analyzes different schemes in terms of daily energy conservation and material selection, and also proves to have carbon reduction effects through the BCFd method. This study also found in the evaluation process that the BCFd can propose many specific material selection suggestions for the characteristics of the project, but a small number of suggestions will conflict with the actual conditions such as regulations, maintenance management, and durability. The results of the paper will be fed back to LCBA, allowing the tool itself to be more integrated with building practices.

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