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*Article*

# Lifecycle $CO_2$ Reduction by Implementing Double Window Casement Systems in Residential Units in Korea

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**Abstract:** This study investigated lifecycle $CO_2$ ($LCCO_2$) emission reductions through application of double-window casement systems (DWCS) in residential units in Korea, compared with conventional single windows (SWs). The DWCS is a double window system that is energy-efficient, reducing energy consumption during operation. However, this system incorporates increased embodied $CO_2$ emissions. We evaluated $LCCO_2$ reductions associated with use of the DWCS by calculating $CO_2$ emissions during space conditioning as well as the embodied $CO_2$ emissions of the DWCS. The results showed that use of DWCS in a residential unit during the cooling season had 26.2 and 27.4 t $CO_2$ fewer emissions than SWs in the natural ventilation and minimum ventilation modes, respectively. Although implementation of DWCS is expected to substantially reduce $LCCO_2$ emissions, the large embodied $CO_2$ emissions of the aluminum frame reduce the benefits of the DWCS.

**Keywords:** double-window system; residential unit; lifecycle $CO_2$; energy simulation

## 1. Introduction

### *1.1. Background*

Recently, climate change has become a difficult challenge for society and governments. There is worldwide agreement on the necessity for mitigation of global warming resulting from increased greenhouse gas (GHG) emissions. GHG emissions are mainly due to anthropogenic sources such as economic activity and consumption of fossil fuels for energy. Under these circumstances, building energy consumption plays an important role. According to the International Energy Agency, residential and commercial buildings are responsible for about 35.9% of energy use globally [1]. Developed countries such as the UK or USA have higher energy consumption in the building sector, making up about 40% of the total national energy consumption [2]. Consequently, many nations have released action plans to mitigate climate change, containing detailed strategies for achieving substantial $CO_2$ reductions. The Korean government has participated in this movement and has announced a plan to reduce $CO_2$ emissions by 30% by 2020. In Korea, building energy consumption accounts for about 30% of the total energy consumption and residential buildings consume 53% of this amount [3]. In addition, residential building construction accounts for more than 40% of new construction. Thus, improvements in the energy efficiency of residential building in Korea are necessary to meet $CO_2$ reduction targets. In many cases, it may be desirable to reduce energy demand by enhancing the performance of passive systems (or the building fabric) before applying more efficient facility or renewable energy systems [4].

Double-layered envelope systems such as double-skin façades are effective in reducing the energy consumption of office buildings and residential buildings [5–12]. The energy-efficient properties of a double-layered envelope system can be maximized by applying natural cooling strategies [13–18]. In addition, a double-layered envelope system can be implemented as a compact window type, the double window system. Double window systems also have energy-saving benefits such as increased thermal resistance, simplicity of solar control and natural ventilation ability [19–30]. Therefore, double window systems could contribute to the reduction of national $CO_2$ emissions in Korea.

### *1.2. Purpose*

The main objective of this study was to evaluate reductions in $LCCO_2$ emissions with the implementation of double-window casement systems (DWCS) in residential buildings in Korea. Conventional double-window systems (DWs) without shading devices are already in use in residential buildings in Korea for heat load reduction. However, because conventional DWs lack built-in shading devices, they permit undesirable solar transmission during the cooling season, increasing the cooling load. In this study, we considered a DWCS, which is a box-type double-skin façade designed to reduce the heating and cooling loads of residential buildings. We evaluated its benefits in terms of lifecycle $CO_2$ ($LCCO_2$) reductions assuming that the DWCS was implemented in a residential building in Korea.

## 2. Methods

To evaluate the potential benefits of the DWCS, we compared the DWCS to conventional single windows (SWs). We first defined the geometry of the DWCS, then evaluated the resulting reductions in heating and cooling loads, and finally performed a complete $LCCO_2$ assessment. We focused on the net $LCCO_2$ change from application of the DWCS due to reduced operating energy and increased embodied energy. Components of the residential building other than the window system were considered to be identical and were not included in the assessment.

An $LCCO_2$ assessment for a building includes quantitative assessment of the total $CO_2$ emissions generated during the entire lifespan of the building. The life cycle of a building is divided into the construction/transportation stage, the operation and maintenance stage, and the demolition and disposal stage. To perform an $LCCO_2$ assessment for a residential building, the life cycle of the building should be divided into these stages and an overall $CO_2$ assessment method should be determined after developing a $CO_2$ assessment approach for each stage [31]. The present assessment included the critical factor of embodied energy, which represents resource consumption during production and transportation. Embodied energy includes all of the primary energy used by a product or process, including fuel and electricity [32]. Estimates of embodied energy for each window system were converted into embodied $CO_2$ emissions.

To evaluate $LCCO_2$ reduction during the operation stage, heating and cooling loads were calculated using the energy simulation model ESP-r (Energy System Performance-research) [33]. ESP-r is an open source energy simulation tool in the fields of various built environments: thermal, visual, electrical and *etc.* This program has been extensively validated by many case studies [34]. Assumed energy consumption for plug load and domestic hot water were added to the operational energy consumption for the $LCCO_2$ assessment. In addition, embodied $CO_2$ emissions for SWs and the DWCS were calculated using $CO_2$ emission factors.

## 3. Window Systems

In contrast to conventional windows such as SWs or DWs used for residential buildings in Korea, DWCS have a shading device between the external and internal windows. Conventional DWs have very little or no cavity space between the external and internal windows, preventing installation of a shading device in the gap. However, the new DWCS window system has a greater cavity depth of 20 cm for shading device installation. In addition, the internal window is designed to tilt and is designed to enhance air-tightness and regulate the natural ventilation rate. A schematic of the DWCS is depicted in Figure 1.

Figure 2 illustrates the operational strategy of the DWCS. When outdoor temperatures are very cold, the external and internal windows are closed for heat loss reduction and all shading is removed to maximize solar radiation. During intermediate seasons, window operation varies with the outdoor air temperature. Under these conditions, the external window is always fully open and the internal window controls the incoming air flow rates. If the outdoor temperature is warm, requiring rapid ventilation of excess heat from the indoor space, the internal window can be fully opened for maximum natural ventilation. Shading is provided during intermediate seasons. When the outdoor air temperature is too hot for natural ventilation, the external window is fully opened to prevent overheating in the cavity between the external and internal windows. The internal window is closed to exclude the hot outdoor air and shading is provided. Mechanical ventilation is provided when natural ventilation is not available. Figures 3 and 4 show the geometries of the SW and DWCS. Window systems consist of aluminum, glass, thermal breaks, and sealant.

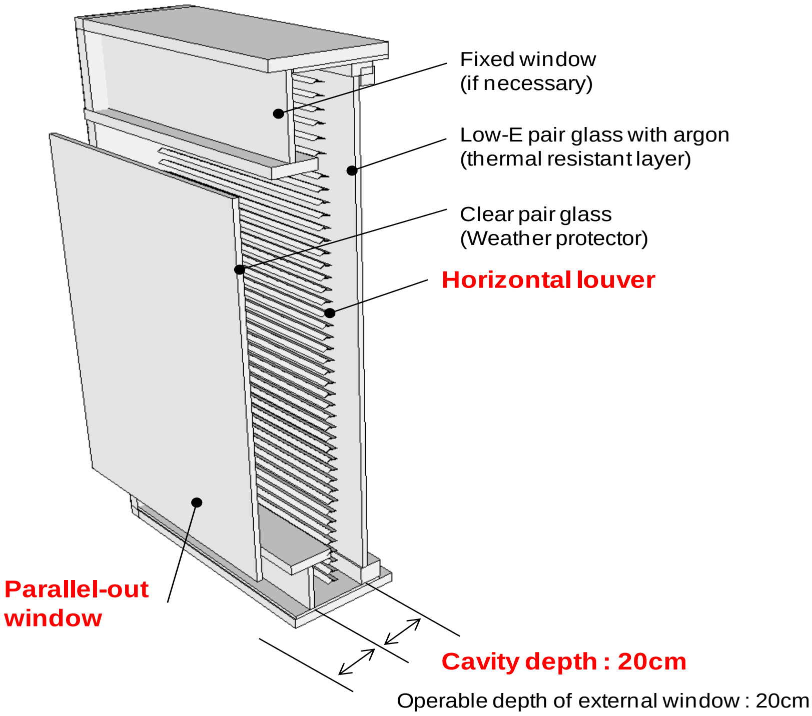



**Figure 1.** Conceptual geometry of the DWCS.

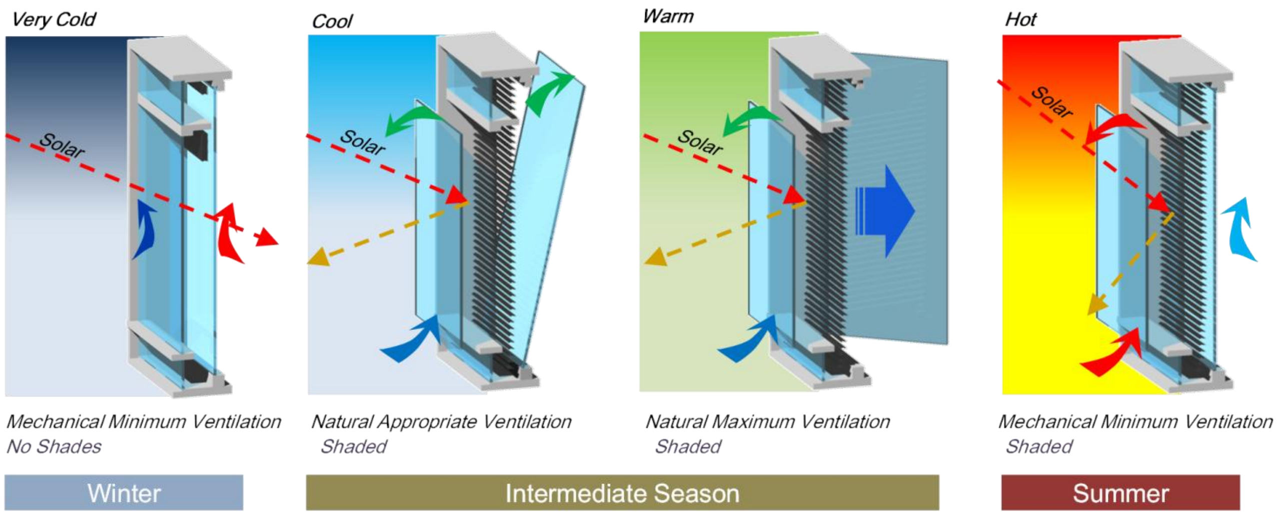



**Figure 2.** Operation of the DWCS.

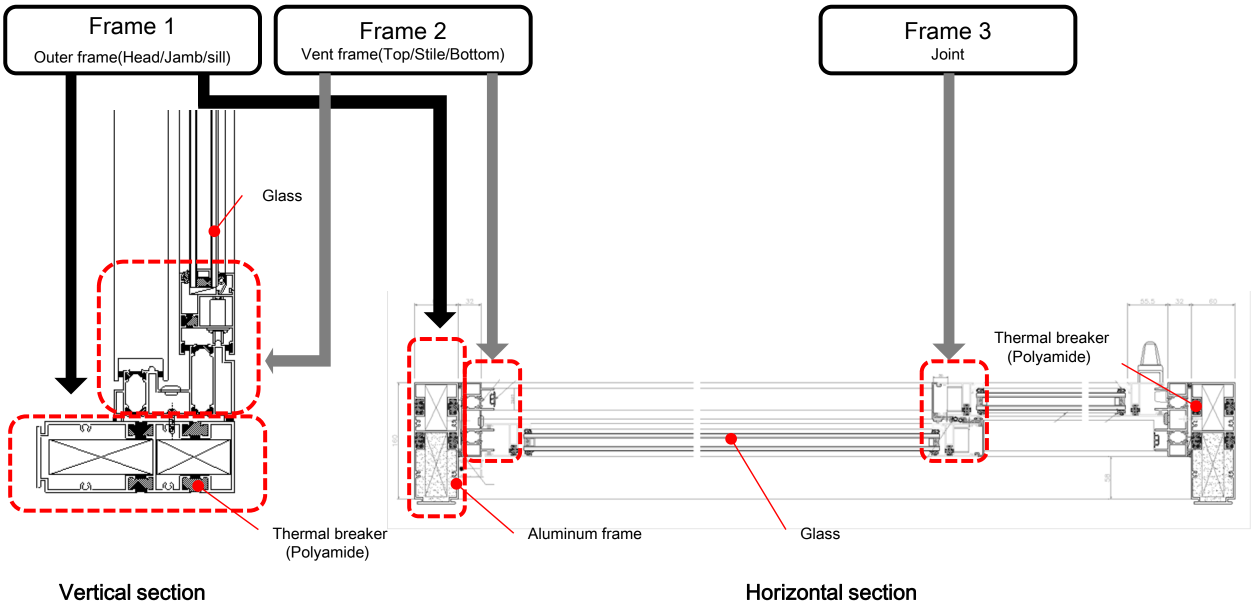



**Figure 3.** Composition of a SW.

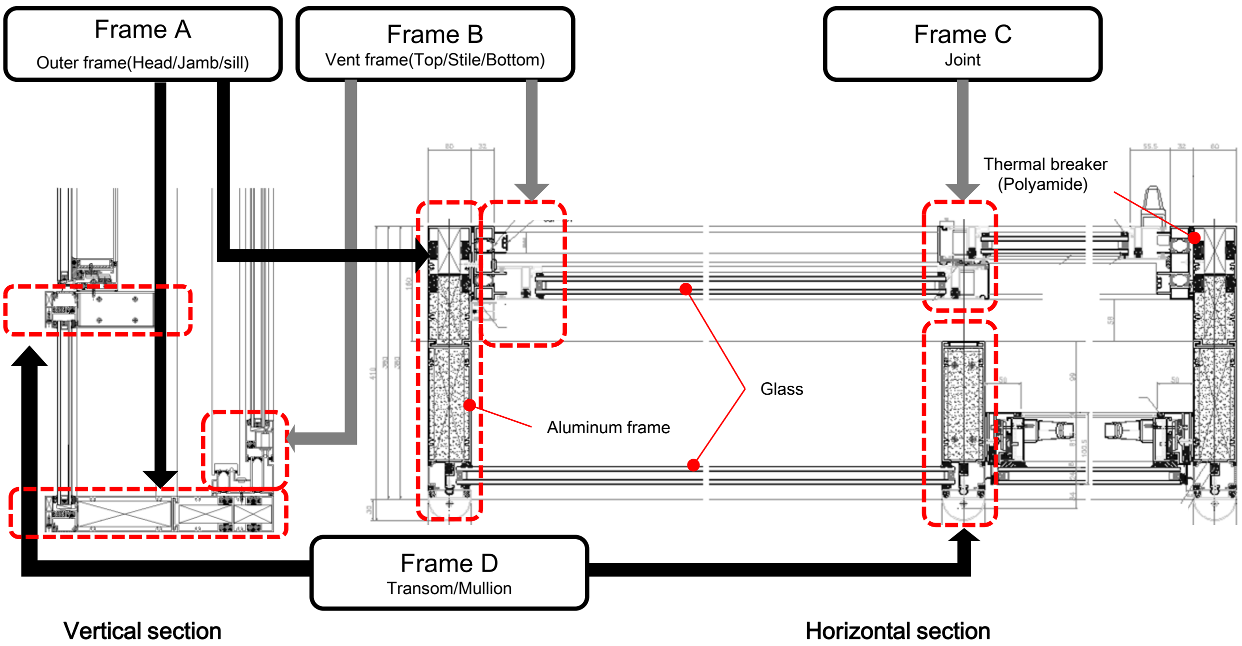



**Figure 4.** Composition of a DWCS.

## 4. $CO_2$ Emissions during Space Heating and Cooling

### *4.1. Target Building*

A residential building adopting DWCS was selected for evaluation of space heating and cooling loads. The target building is located in Incheon, Korea. The target building and the configuration of the selected residential unit are depicted in Figures 5 and 6. The building and most of the windows are installed on the main façade and facing southeast. The climate in this region is hot and humid during summer and cold and dry during winter. Such a climate pattern results in drastic variations in heating and cooling energy consumption with seasonal change.


**Figure 5.** Target building.

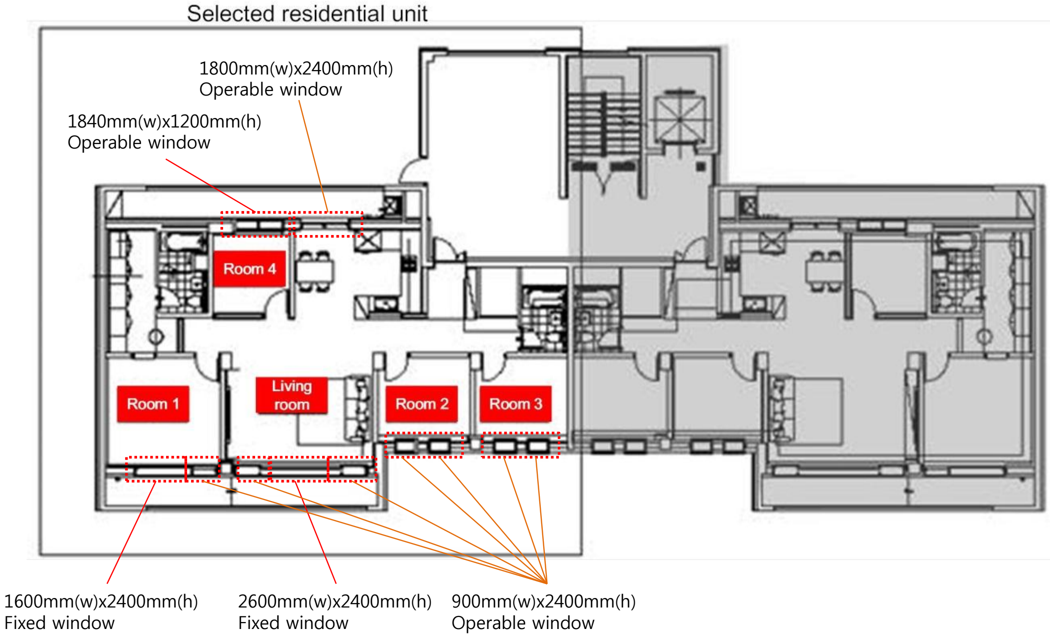



**Figure 6.** Selected residential unit and window geometry.

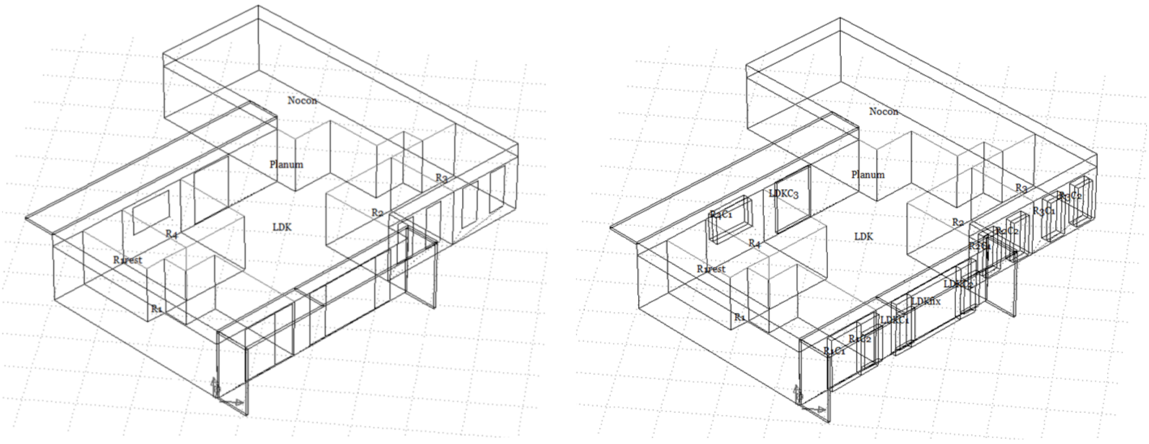
Table 1 lists the materials used for windows in the target residential unit, in the case of SW and DWCS. The total volumes of the materials used for manufacturing were calculated using a CAD program. Sectional areas and lengths of the window components were obtained and multiplied to calculate the frame volume.

**Table 1.** Materials in windows per residential unit.

| Item | SW | DWCS |
| --- | --- | --- |
| Frame ($cm^3$) | 177,643 | 271,156 |
| Glass ($m^2$) | 45.6 | 91.2 |
| Polyamide ($m^3$) | 0.09 | 0.33 |

*4.2. Simulation Inputs*

To estimate the heating and cooling loads, an energy simulation was performed. To compare SWs and the DWCS, two different simulation models were established. Simulation model images developed by the dynamic simulation model tool ESP-r are depicted in Figure 7. Simulation cases for the comparative study are presented in Table 2. Cases 1 and 3 assumed SWs with low thermal resistance and an internal shading device. Cases 2 and 4 assumed implementation of the DWCS for improved thermal performance. The optical and thermal performances of the window systems are shown in Tables 3 and 4. The U-factor of the external wall was set to 0.3 W/m$^2$·K.




(**a**) (**b**)

**Figure 7.** Residential unit modeling by ESP-r of (**a**) Model 1 (SWs) and (**b**) Model 2 (DWCS).

**Table 2.** Simulation cases.

| Case | Window | Ventilation Mode |
|---|---|---|
| Case 1 | SWs | Minimum ventilation |
| Case 2 | DWCS | (0.7 ACH) |
| Case 3 | SWs | Natural ventilation |
| Case 4 | DWCS | |

**Table 3.** Properties of the SWs.

| Item | External Window |
|---|---|
| **Modeling Module** | **CFC (Complex Fenestration Construction)** |
| Outer glazing | Solar transmission: 0.771<br>Reflection (front): 0.070<br>Reflection (back): 0.070 |
| Inner glazing | Solar transmission: 0.771<br>Reflection (front): 0.070<br>Reflection (back): 0.070 |
| Shading device | Depth: 50 mm<br>Angle: 45° |
| Overall U-factor (including frame) | 3.0 W/m$^2$·K |

**Table 4.** Properties of the DWCS.

| Item | External Window | Internal Window |
|---|---|---|
| Module | CFC<br>(Complex fenestration construction) | TMC<br>(Transparent multi-layer construction) |
| Outer glazing | Solar transmission: 0.771<br>Reflection (front): 0.07<br>Reflection (back): 0.07 | Solar transmission: 0.514<br>Absorption (front): 0.182<br>Absorption (back): 0.138 |
| Inner glazing | Solar transmission: 0.771<br>Reflection (front): 0.07<br>Reflection (back): 0.07 | |
| Shading device | Depth: 50 mm<br>Angle: 45° | - |
| Overall U-factor<br>(including frame) | 3.0 W/m$^2$·K | 2.0 W/m$^2$·K |

To appropriately operate each window system, separate control methods were adopted for the heating and cooling seasons. Control strategies during the cooling period are shown in Table 5. Two ventilation strategies were established, cross-ventilation and single-sided ventilation. When the outdoor air was a comfortable temperature, cross-ventilation was used. However, if the indoor temperature approached the cooling or heating set-point temperature, the doors were closed and the ventilation mode was changed to single-sided. This mode reduces outdoor air intrusion to the indoor space and maintains a moderate indoor temperature. For the space cooling device, a package air conditioning system (PAC system) was selected and the basic heating and cooling module (ideal heating/cooling calculation module) was used to represent the air cooling system in ESP-r. The cooling set-point temperature was 26 °C. During the heating season, minimum ventilation of 0.7 ACH (Air Change per Hour) was applied by a mechanical ventilator to the indoor space and an infiltration rate of 0.36 ACH was assumed for the cavity space of the DWCS. Korean residential buildings typically have a traditional radiant floor heating system, known as *ondol*. Thus, heat flux was provided to the floor fabric to simulate this floor heating model. A total of 25 kW of boiler energy was applied and the maximum heat flux to the each room was proportional to the floor area. The indoor heating set-point temperature was 20 °C. These heating and cooling methods are depicted in Figure 8.

The air-flow network (AFN) of the energy simulation used the standard orifice model to evaluate natural ventilation effects as expressed by Equation (1). The simulation used a fixed discharge coefficient ($C_d$ = 0.65). The operable window areas in the partially and fully open conditions are shown in Table 6. The operable areas of the SW and internal window of the DWCS were controlled by the outdoor air temperature:

$$Q = C_d \cdot A \cdot (2 \cdot \frac{|\Delta P|}{\rho})^{\frac{1}{2}} \quad (1)$$

$Q$: Mass flow (kg/s); $C_d$: Discharge coefficient; $\Delta P$: Pressure difference (Pa); ρ: Fluid density (kg/m$^3$); $A$: Area of opening (m$^2$).

Climate data for Incheon in 2010 were used for the simulation. ESP-r provides a module that converts the climate data format from that of the Korea Meteorological Administration (KMA). Thus, global horizontal solar radiation data furnished by KMA was used in the simulation and diffuse radiation was calculated by the climate modification module of ESP-r, which uses the Muneer model.

**Table 5.** Window control strategies during the cooling season.

| Category | Control Strategies |
| --- | --- |
| Cooling equipment | Set point temperature: 26 °C<br>Operating period: 00:00–24:00<br>Cooling device module for the simulation: Ideal cooling |
| Ventilation strategy | Cross ventilation conditions:<br>- Window operation reflects the outdoor temperature ($T_o$)<br>- Indoor doors are fully open<br>- Window operation 1 (SW and internal window of DWCS):<br>23 °C > $T_o \geq$ 20 °C: partially open,<br>25 °C > $T_o \geq$ 23 °C: fully open,<br>$T_o$ < 20 °C or ≥25 °C: closed<br>- Window operation 2 (external window of DWCS)<br>$T_o \geq$ 20°C: fully open<br>$T_o$ < 20 °C: closed<br>Single-sided ventilation conditions:<br>- Operates the indoor doors based on the indoor temperature ($T_i$)<br>- $T_i$ > 25.5 °C or <20.5 °C: close indoor doors |

**Table 6.** Operable window area for natural ventilation.

| Item | Living Room | | R1 | R2 | R3 | R4 |
| --- | --- | --- | --- | --- | --- | --- |
| | South | North | South | South | South | North |
| Floor area ($m^2$) | 60 | | 24 | 12 | 12 | 11 |
| Fully opened ($m^2$) | 1.3 | 2.4 | 1.3 | 1.3 | 1.3 | 1.3 |
| Partially opened ($m^2$) | 0.3 | 0.55 | 0.3 | 0.3 | 0.3 | 0.3 |

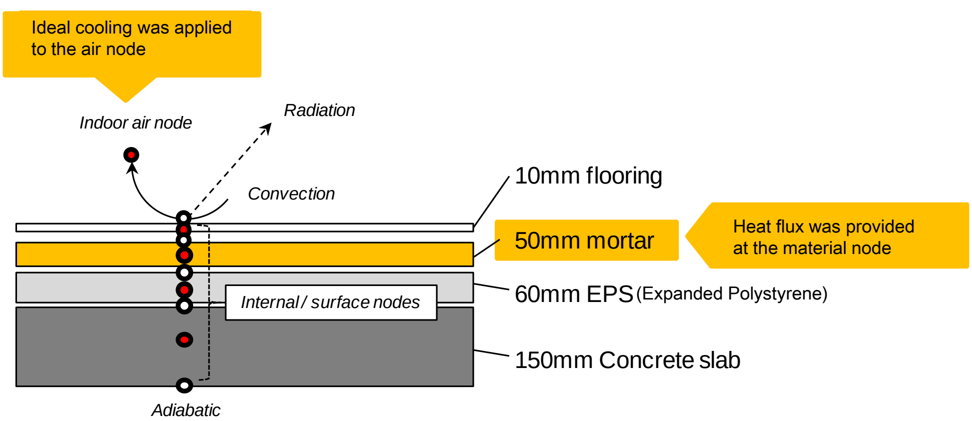



**Figure 8.** Heating and cooling methods in the energy simulation.

*4.3. Results*

The calculated annual space heating and cooling energies are shown in Table 7 and Figure 9. The heating load was reduced by about 23% when the DWCS was used, regardless of the ventilation conditions. On the other hand, the cooling load was reduced by 46% and 61% in the minimum ventilation and natural ventilation modes, respectively, with implementation of the DWCS. The average natural ventilation rates of Cases 3 and 4 during cooling period are 20.2 air changes per hour (ACH) and 12.9 ACH respectively. Thus, energy savings are increased by natural ventilation during the cooling season. The average ventilation rate of DWCS is lower than SW. The heating load made up the majority of the overall space conditioning load. Based on this annual total heating and cooling load analysis, the DWCS reduced energy consumption under all ventilation conditions.

**Table 7.** Calculated heating and cooling loads.

| Case | Window Type | Ventilation Mode | Heating Load (kWh) | Cooling Load (kWh) |
|---|---|---|---|---|
| Case 1 | SW | Minimum | 12,540 | 4,183 |
| Case 2 | DWCS | Minimum | 9,662 | 2,277 |
| Case 3 | SW | Natural | 12,540 | 2,830 |
| Case 4 | DWCS | Natural | 9,673 | 1,098 |

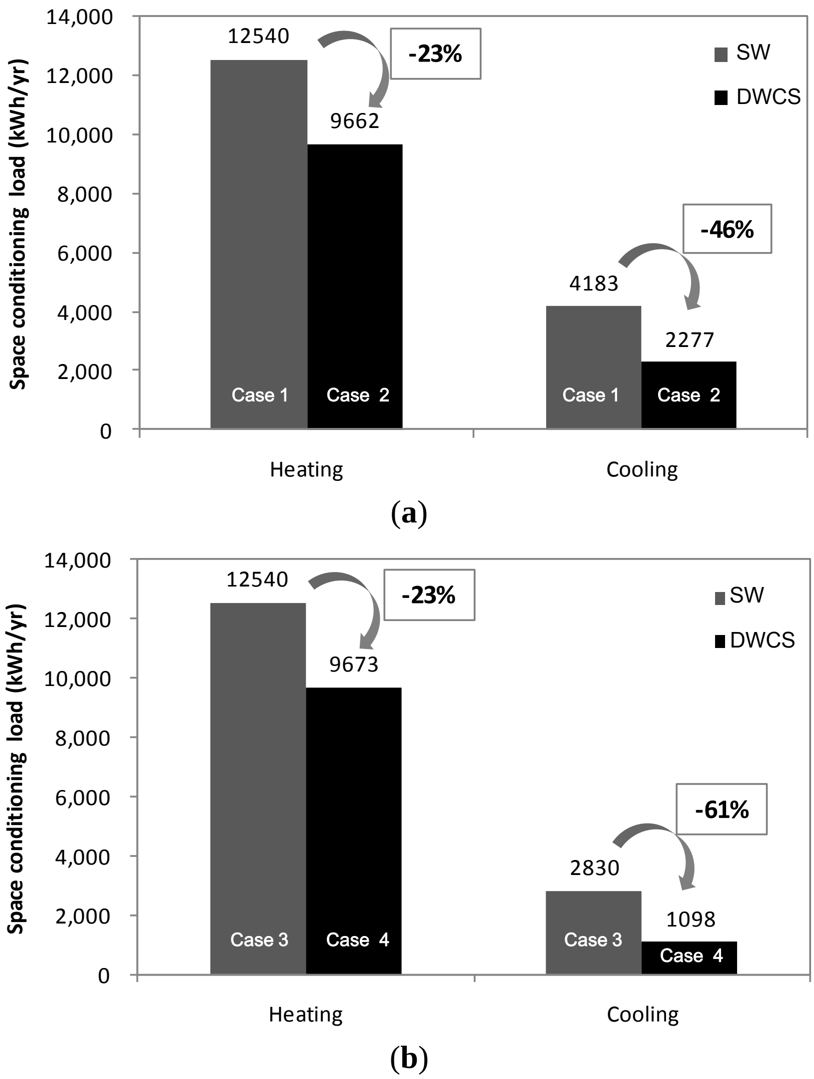



**Figure 9.** Space conditioning load reduction: (**a**) minimum ventilation conditions and (**b**) natural ventilation conditions.

## 5. Lifecycle $CO_2$ Emissions Assessment

### *5.1. Lifecycle $CO_2$ Assessment Overview*

$LCCO_2$ assessment includes the entire lifespan of a building. In this study, we considered the following three stages: (1) the construction and transportation stage; (2) the operation and maintenance stage; and (3) the demolition and disposal stage. $CO_2$ emissions during the operation stage were calculated based on the energy simulation, which determined the heating and cooling loads. These results were used as input data for $CO_2$ emissions during the operation stage. $CO_2$ emissions during the construction stage can be calculated by inter-industry analysis. $LCCO_2$ inventories in Korea generally furnish data in the form of $CO_2$ emissions per unit cost. However, recent studies have developed a limited $LCCO_2$ inventory consisting of mass- or volume-based data. In this study, embodied $CO_2$ emissions during the construction process were calculated using the results of evaluated heating and cooling load in advance. $CO_2$ emissions during transportation, maintenance, and the demolition and disposal stage are difficult to calculate; we roughly assumed that these stages required about 30% of the embodied $CO_2$ emissions of the window system [31,35].

### *5.2. $CO_2$ Emissions during Operation*

The end-use energy consumption of the residential unit is calculated by using the evaluated heating and cooling loads. Subsequently, $CO_2$ emissions during the operation stage were calculated. Heating and cooling loads were converted to end-use energy using the efficiency of the space conditioning equipment. The residential unit was assumed to use a gas boiler as the heating device and a PAC system as the cooling device. Natural gas was assumed to be the heat source for the boiler and electricity was assumed to be the energy source for the PAC system. End-use energy consumption was obtained as follows:

$$\text{Natural gas consumption (m}^3\text{)} = \frac{\text{Heating load (kWh)/Boiler efficiency}}{\text{Lower calorific value of natural gas}} \quad (2)$$

$$\text{Electricity consumption for cooling (kWh)} = \frac{\text{Cooling load (kWh)}}{\text{Coefficient of performance}} \quad (3)$$

Key input values for calculating the end-use energy consumption are presented in Table 8.

**Table 8.** Values for end-use energy calculation.

| Factor | Input Value |
|---|---|
| Boiler efficiency | 85% |
| Coefficient of performance of the PAC system | 2.7 |
| Low calorific value of natural gas | 11.1 kWh/N·m$^3$ |

In addition to the heating and cooling energy, energy consumption for heating domestic hot water and electricity for plug load were estimated. The base energy consumption was calculated as follows:

$$\text{Heat energy for hot water(MJ)} = 14{,}504 \quad (4)$$

$$\text{Plug load (MJ)} = 98.7 \cdot A + 5965 \quad (5)$$

where $A$ is the floor area of the residential unit (m$^2$).

The Korean government uses this equation to evaluate the performance of low-energy housing [36]. These equations express the typical energy consumption of the baseline model, conventional residential buildings. The total floor area of the residential unit of the target building was 119 $m^2$.

The $CO_2$ emissions factor is multiplied with the end-use energy consumption to obtain the $CO_2$ emissions during operation stage. $CO_2$ emissions factors for each energy source, natural gas and electricity, are shown in Table 9 [37].

**Table 9.** $CO_2$ emissions factors by energy source.

| Energy Source | Emissions Rate |
|---|---|
| Natural gas | 0.00259 t $CO_2/N{\cdot}m^3$ |
| Electricity | 0.469 t $CO_2$/MWh |

The calculated annual end-use energy consumption for each case for the residential unit is shown in Table 10. In addition, estimated yearly $CO_2$ emissions are depicted in Figures 10 and 11. Annual $CO_2$ emissions from heating and cooling energy were reduced by 26.9% under minimum ventilation conditions and 27.7% under natural ventilation condition. Reductions in the heating load contributed much more than reductions in the cooling load to annual $CO_2$ emissions reductions due to implementation of the DWCS. When the hot water and plug load were considered, annual operational $CO_2$ emissions were reduced by 15% under both minimum ventilation conditions and natural ventilation conditions.

**Table 10.** Annual end-use energy consumption.

| Case | Window Type | Ventilation Mode | Natural Gas ($m^3$) | Electricity (kWh) |
|---|---|---|---|---|
| Case 1 | SW | Minimum | 1756 | 6218 |
| Case 2 | DWCS | Minimum | 1451 | 5513 |
| Case 3 | SW | Natural | 1756 | 5715 |
| Case 4 | DWCS | Natural | 1451 | 5076 |

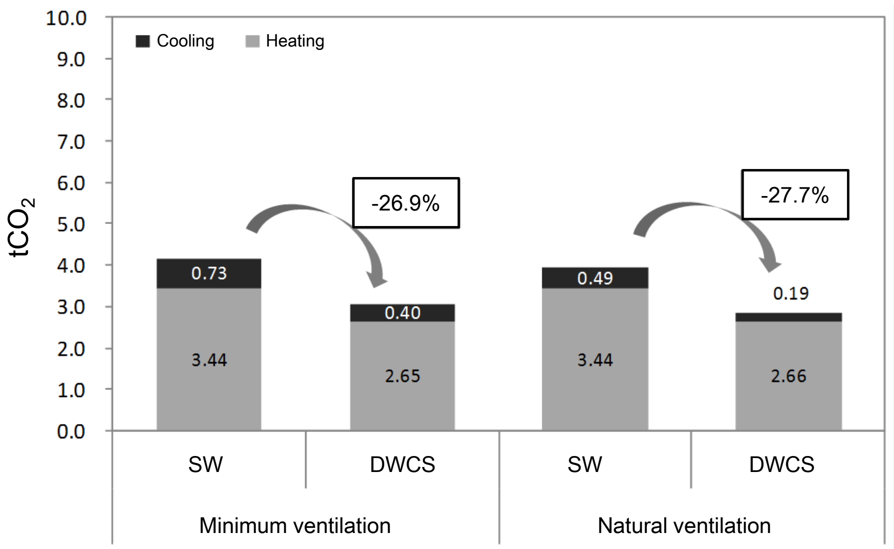



**Figure 10.** Reduction in annual $CO_2$ emissions for space conditioning.

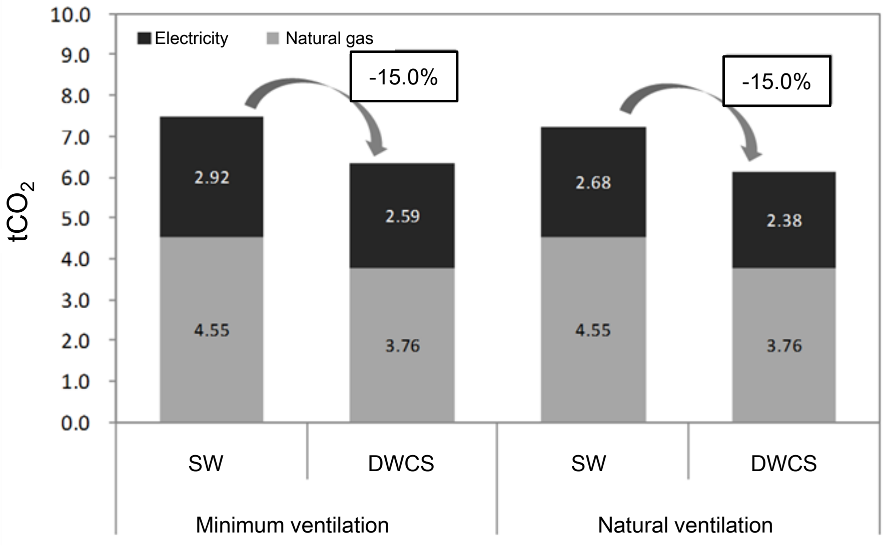



**Figure 11.** Reduction in annual $CO_2$ emissions for overall operation.

### *5.3. Evaluation of Embodied $CO_2$ Emissions*

In this study, the embodied $CO_2$ emissions of the aluminum frame, glass, and thermal break were included, as these make up nearly the entire volume of the window systems. Sealants and other components were considered accessory materials.

Embodied $CO_2$ emissions were estimated considering the amounts of the materials required to manufacture the SW and DWCS, as follows:

$$\text{Embodied } CO_2 \text{ emissions} = \text{Volume} \times \text{Density} \times CO_2 \text{ emissions factor} \quad (6)$$

Embodied $CO_2$ emissions per material unit area or weight are shown in Table 11 [38]. We assumed that all of the materials were manufactured in Korea. Table 12 shows the density of the aluminum used for frame manufacturing.

**Table 11.** Embodied $CO_2$ emissions factor.

| Material | Unit | $CO_2$ Emissions (domestic material) (kg $CO_2$/unit) |
|---|---|---|
| Glass | $m^2$ | 26.3690 |
| Metal window frame | kg | 17.3816 |
| Polyamide (thermal break) | kg | 751.5498 |

**Table 12.** Material properties.

| Material | Density |
|---|---|
| Aluminum | 2.7 $g/cm^3$ |
| Polyamide | 1.1 $g/cm^3$ |

As noted above, $CO_2$ emissions during the maintenance and disposal stage and other stages were added to the embodied $CO_2$ emissions [31,35]. Detailed percentages are as follows relative to $CO_2$ emissions during the material production process: accessory materials (2%), transportation and installation (5.5%), maintenance (10%), and demolition and disposal (12.5%).

The amounts of the embodied $CO_2$ emissions for the residential windows are shown in Table 13. The aluminum frame accounted for the majority of the embodied $CO_2$ emissions. The total embodied $CO_2$ emissions of the SW and DWCS were 12.4 and 21.1 t $CO_2$, respectively, relatively large values. For SWs, the embodied $CO_2$ emissions were about 1.64–1.70 times the annual $CO_2$ emissions from operations, while the DWCS embodied $CO_2$ emissions were 3.27–3.38 times larger than those of annual operations. Based on these results, use of an aluminum frame in the DWCS may not be ideal to achieve $LCCO_2$ reductions.

**Table 13.** Total embodied $CO_2$ emissions.

| $CO_2$ Emissions (domestic material) t $CO_2$ | SW | DWCS |
|---|---|---|
| Frame | 8.3 | 13.6 |
| Glass | 1.2 | 2.4 |
| Polyamide | 0.06 | 0.24 |
| Other | 2.87 | 4.80 |
| Total | 12.4 | 21.1 |

*5.4. Assessment Results*

To calculate the $LCCO_2$, we assumed that the life spans of residential buildings and window systems are 40 and 20 year, respectively. Lots of Korean local governments set the life span of residential building to 40 year [39]. Korean building code suggests 10 year and 25 year as the life spans of aluminum window systems for partial and full renovation, respectively [40]. In this evaluation life span of the window systems is assumed to 20 year, half of the building life span.

The assessment results are shown in Tables 14 and 15. In minimum ventilation mode, implementation of the DWCS reduced $CO_2$ emissions by 27.4 t $CO_2$ over the lifecycle of the residential unit. In natural ventilation mode, about 26.2 t $CO_2$ emissions were reduced.

**Table 14.** Calculated $LCCO_2$ emissions.

| Window | Ventilation Mode | $LCCO_2$ Emissions (t $CO_2$) | |
|---|---|---|---|
| | | Operating | Embodied |
| SW | Minimum ventilation | 298.8 | 24.8 |
| DWCS | | 254.0 | 42.2 |
| SW | Natural | 289.2 | 24.8 |
| DWCS | Ventilation | 245.6 | 42.2 |

**Table 15.** Calculated $LCCO_2$ reduction.

| Window | Ventilation Mode | $LCCO_2$ Emissions (t $CO_2$) | Total Reduction (t $CO_2$) |
|---|---|---|---|
| SW | Minimum ventilation | 323.6 | - |
| DWCS | | 296.2 | 27.4 |
| SW | Natural ventilation | 314.0 | - |
| DWCS | | 287.8 | 26.2 |

## 6. Conclusions

In this study, we calculated the reduction in $LCCO_2$ emissions due to implementation of DWCS instead of SWs in a residential building in Korea. The results can be summarized as follows:

(1) A total of 26.2–27.4 t $CO_2$ was reduced by implementation of the DWCS rather than SWs in the residential unit in Korea.
(2) Most of the reduction in $LCCO_2$ emissions resulted from reduced heating energy consumption. Reductions in cooling energy were comparatively small for the residential unit.
(3) The aluminum frame incorporated very high embodied $CO_2$ emissions and reduced the $LCCO_2$ benefits of the DWCS system.

Based on these results, implementation of the DWCS can reduce $LCCO_2$ emissions. However, the $CO_2$ emissions benefits are substantially reduced by the high embodied $CO_2$ emissions of the larger aluminum frame of the DWCS. Optimization of the frame material and geometry are suggested to further reduce $LCCO_2$ emissions.

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## Author Contributions

Chang Heon Cheong designed the study and contributed to the simulation and writing the manuscript. Taeyeon Kim and Seung-Bok Leigh contributed to the analysis and writing the manuscript.

## Conflicts of Interest

The authors declare no conflict of interest.

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