Global Journal of HUMAN-SOCIAL SCIENCE: E
Economics
Volume 21 Issue 6 Version 1.0 Year 2021
Type: Double Blind Peer Reviewed International Research Journal
Publisher: Global Journals
Online ISSN: 2249-460x & Print ISSN: 0975-587X

Resolution of the M-Shape Pattern of the Outdoor Air Temperature Environmental Kuznets Curve (EKC) for Metropolitan Areas in a Country: Using Long-Term Monthly Level Data of Taipei City as Empirical Evidence

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Abstract- In Taiwan, the heat island effect is the most significant in Taipei City. Thus this research provides a causal explanation for why urban outdoor air temperature has an M-shape EKC pattern for metropolitan areas in a country. Results show that the growth rate change in CO2 concentration can induce changes to the periods of the La Nino effect and El Nino effect, causing high fluctuations in rain accumulation. The amount of rain then alters A-type evaporation, and so the evaporation amount is the top factor for the diffusion of a city's heat. This fluctuation plays as a cooling and heating source for the V region of the M shape in the outdoor air temperature EKC pattern. In our previous studies, the growth rate change in CO2 concentration correlates to the energy structure. Therefore, a heat sinking model has been proposed to explain the accumulation of heat in a city, in which a proportion process for the solar irradiation source from buildings and remodeling engineering from a public housing policy and the private sector can play as a heating source of the two peaks of the M shape and present long-term linear growth in the outdoor air temperature EKC pattern.

Keywords: *environmental kuznets curve, v-shape, remodeling.*

GJHSS-E Classification: *FOR Code: 149999*

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Resolution of the M-Shape Pattern of the Outdoor Air Temperature Environmental Kuznets Curve (EKC) for Metropolitan Areas in a Country: Using Long-Term Monthly Level Data of Taipei City as Empirical Evidence

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Abstract- In Taiwan, the heat island effect is the most significant in Taipei City. Thus this research provides a causal explanation for why urban outdoor air temperature has an M-shape EKC pattern for metropolitan areas in a country. Results show that the growth rate change in CO_2 concentration can induce changes to the periods of the *La Nino effect* and *El Nino effect*, causing high fluctuations in rain accumulation. The amount of rain then alters A-type evaporation, and so the evaporation amount is the top factor for the diffusion of a city's heat. This fluctuation plays as a cooling and heating source for the V region of the M shape in the outdoor air temperature EKC pattern. In our previous studies, the growth rate change in CO_2 concentration correlates to the energy structure. Therefore, a heat sinking model has been proposed to explain the accumulation of heat in a city, in which a proportion process for the solar irradiation source from buildings and remodeling engineering from a public housing policy and the private sector can play as a heating source of the two peaks of the M shape and present long-term linear growth in the outdoor air temperature EKC pattern. The heat-island effect could be addressed by controlling the re-modeling timing when the CO_2 concentration is fixed through maintaining the energy structure of a country.

Keywords: environmental kuznets curve, v-shape, remodeling.

I. Introduction

The definition of "outdoor air temperature" is the temperature between the urban canopies from the ground surface. This is the significantly environment contributed by human activities. The definition of "surface temperature" is the heat emitted from the soil, ground surface, and buildings. Previous works have found that the factors contributing to the formation of an urban heat island effect are caused by urbanization and climate change effects (Aekbal Salleh et al., 2013; Miao and Chen, 2014; Yang et al., 219; Yunfei et al., 2020).

Taiwan's urbanization is over 79%, while the average for the world is 52%. The literature has proposed the urban heat island effect to describe the problem of using fossil energy along with thermal-isolated building materials in tall buildings that would cause an increase in urban outdoor air temperatures. In recent 20 years, global warming and increasing CO_2 concentration have become challenges in the world. The correlations among the greenhouse effect, global warming effect, heatwave and the urban heat island effect have spurred official arguments that reducing of carbon emissions is necessary for slowing down global warming. In the future, the carbon tax for the imported good is being adopted by the EU in 2026 to force major manufacturing countries to use renewable energy, including natural gas.

The Environmental Kuznets curve (EKC) was proposed for the environment from income-driven actions (Kuznets, 1955; Grossman and Krueger, 1991; Stern, 2004; Egli and Steger, 2007; Yu and Chen, 2012; Kong and Khan, 2019). From data spanning 1985 to 2015 in Taiwan, the primary-energy consumption-to-GDP ratio (called energy intensity) exhibits an EKC pattern (an inverted U-shape of primary-energy consumption along with increasing GDP). Our previous study found the turning point of primary energy EKC to be driven by an exogenous event to endogenous policy (Huang, 2020). The formation mechanism of CO_2 emission amount is a perfectly inverted V-shape due to the disproportion process of electric energy (Huang, 2021). Most studies in the literature have compared cross-country data and formulated a mathematic equation for a long period. In our previous paper, we have developed an event-induced mechanism (Huang, 2020) to explain the formation of an EKC pattern at the single country level within the Kuznets' 15-25 years. In our previous paper we have developed a new methodology to explain why CO_2 concentration still maintains growth even when Taiwan has significantly reduced the emission amount of CO_2 due to natural gas becoming a growing source of energy (Huang, 2021). This paper aims to find the key factors attributed to the increase in outdoor air temperature.

II. Methods

The panel data used in this paper were collected from the open-source of Taipei City's official website (https://www.gov.taipei/) and Taiwan's Central Weather Bureau (https://www.cwb.gov.tw/). Most of the raw data are in Chinese.

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III. Results

Based on our previous publications, the EKC pattern can be a linear growth type. Figure 1 shows the growth pattern of atmospheric temperature for Taipei City from 1996 to 2021. For one-tail hypothesis testing, we use the 5% significance level, and thus Z*> 1.69. Here, H0 is observed to be 25 between 1996 to 2021, with a standard derivation of "s" years. The Kuznets infrastructural investment cycle is estimated at 15 to 25 years, and in this paper, we choose 23 years (x), and the observed average value is 25 years (H0). If H0 is not being rejected, then the Z value must be higher than Z*. The calculated value of s* is < 4.1 years. From Figure 1, the observed value of s is 2.0 years, which meets the calculated value. Therefore, the outdoor air temperature data span 1998-2021, and the duration meets the EKC time scale. However, the EKC pattern usually is in an inverted U-shape or inverted V-shape, and in Fig. 2, we observe a V-shape. Therefore, we recognize that this period of outdoor air temperature adheres to the Kuznets curve and is not the environmental Kuznets curve, which means that the air temperature is not an environmental concern for people. There is no need to change their behavior for reducing the air temperature. The whole period in Fig. 1 is composed of several curves covering shorter periods.

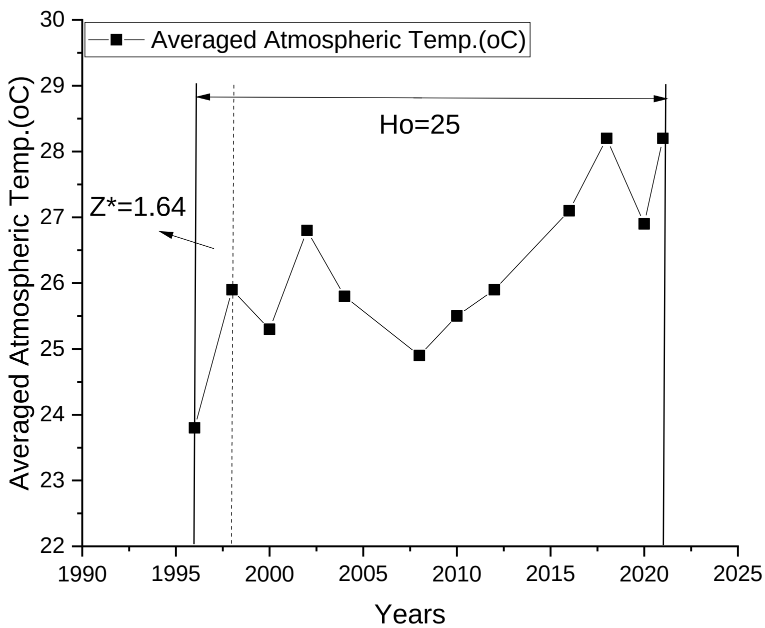

Figure 1: Outdoor Air Temperature of Taipei City for 1996-2021.

Figure 2 compares the city's population and outdoor air temperature of Taipei. We observe the onset of growth in the city's atmospheric temperature starts since 2008, while the onset point in the city's population has begun since 2010. The most significant difference is observed between 2016 to 2021. Therefore, we note that the population is not the major contributor to the atmospheric temperature or the urban heat island effect at a single-city level in Taiwan. The increase in CO_2 emissions and the outdoor air temperature has pushed the theory that CO_2 is the major contributor to global warming, and global warming heats the urban atmospheric temperature. If global warming is a wholly environmental issue, then it should behave like a universal phenomenon for all of Taiwan. Still, after we compared the history data of air temperature for the country's biggest six cities, only Taipei City has the highest temperature increment in the past 25 years. If our observation is correct, then the key contribution of the urban heat island effect might not be from CO_2 directly, so a clear cut-off relation between hot wave and heat island effect should be clarified.

Taipei is a metropolitan area as well as the capital. In recent years, the population has started moved to neighborhood cities (Fig. 1). In addition, the highest urban heat island effect has occurred in Taipei for ten years, since 2010. Taipei City also has a very high density of tall buildings, and the age of those buildings is 35 years old, which is the highest among the six major cities in Taiwan. Therefore, this city provides a perfect condition to ignore the contribution of humans' life activities on heat emissions and consider physical factors that contribute to the heat island effect. Taiwan is an island country and has a small area. Therefore, CO_2 concentration can be treated as homogenous for all of Taiwan, and so the global warming effect is not the major issue for the urban heat island effect in Taipei City. The urban heat island effect is indeed occurred in Taipei City, but the hottest sites caused by heatwave in Taiwan are not in Taipei City.

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Therefore, the heatwave is not the dominated contributor to the urban heat island effect of Taipei City. This study aims to find the dominant factors contributing to the urban heat island effect in Taipei City.

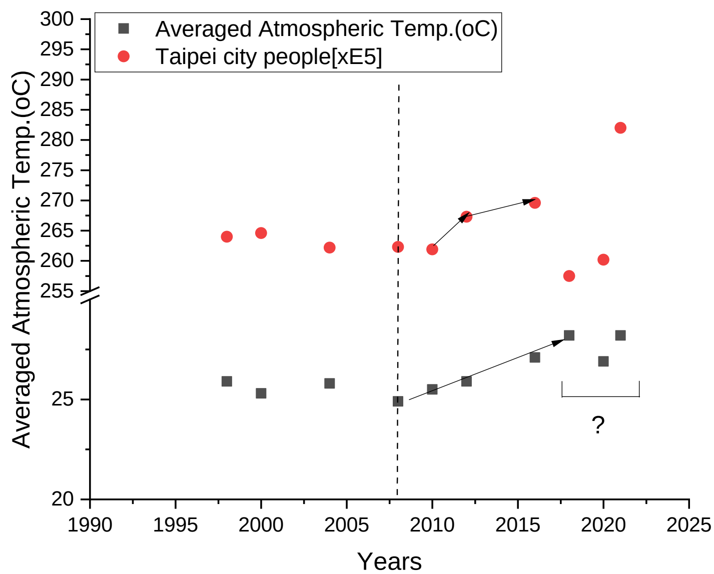

Figure 2: Population and Atmospheric Temperature of Taipei City for 1998-2021.

To identify the major contributors to atmospheric temperature, we employ our previously developed methodology. Linear growth with a stepwise fluctuation on the atmospheric temperature EKC in Taipei shows at least two contributors from various sources. We define this kind of growth model as the "proportional process" shown in Scheme 1. The two major contributors to atmospheric temperature in Taipei City are classified as "human heat source" and "constrained emission potential heat from buildings/ road sinks." These two heat sources contribute to atmospheric temperature individually, and that is why we observe that atmospheric temperature has a linear growth with a stepwise fluctuation. The fluctuation usually is contributed from the potential heat released from buildings/road sinks or human heat sources.

We consider another heating model shown in Scheme 2 that we define as a "disproportional process." In such heating model, solar irradiation heats the atmospheric temperature at first, followed by a heating of buildings/roads by the hot outdoor air temperature. The potential heat of buildings/road sinks combines with the human heat source to heat the outdoor air temperature again. In such a process, we expect that the outdoor air temperature shows an inverted V-shape, at once stopping the growth of the population. However, the population in Taipei City shows constant increment from 1998 to 2008 and even a slight decrease between 2016-2020 (Fig. 1). However, we observe that the atmospheric temperature keeps increasing for 2016-2018. Therefore, we make sure the model will follow Scheme 1 rather than Scheme 2.

Another reason to check Scheme 1 might be a suitable model is based on the fact that 35% of solar irradiation is reflected outer space by clouds; 18% of solar irradiation is absorbed by the atmospheric environment; 47% of solar irradiation is absorbed by the earth's surface. In a rural region, the surface is surface water, soil, and plants, while in a city region, the surface is roads and exterior walls of buildings. When surface absorbs solar irradiation, the potential heat will be kept inside the pavement level and concrete structure, respectively, due to high thermal conductivity. In other words, when there are more buildings, the absorbed potential heat increases, if the building does not transport the heat to the underground level (soil), then a higher atmospheric temperature can be expected. Such heat inside the concrete structure of a building will be transported to the soil. That is why the atmospheric temperature can maintain equilibrium, and even the heat island effect occurs, the strength is at the range of 3-4°C in Taiwan.

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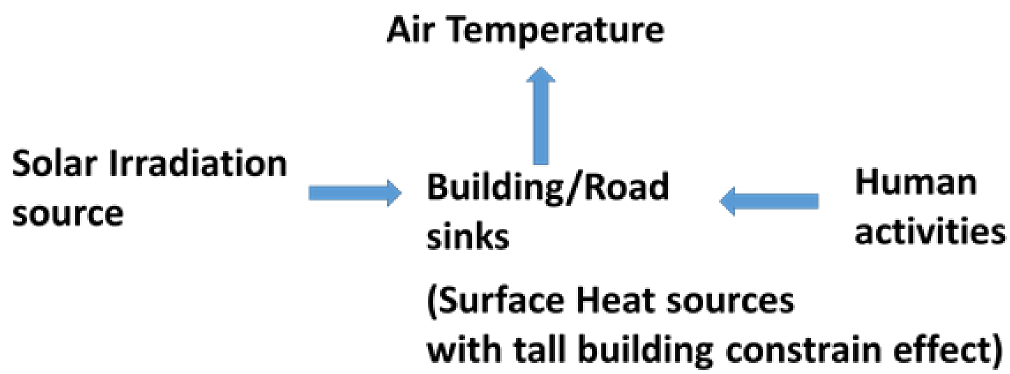
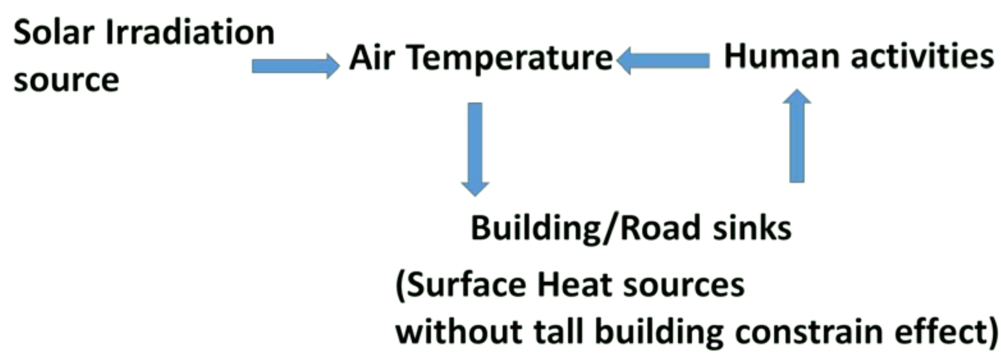


Scheme 1: The proposed proportion process of direct solar irradiation and constrained emissions from buildings/road sinks on the heating of air temperature in Taipei City.



Scheme 2: The proposed disproportion process of direct solar irradiation and non-constrained emissions from human activities on the heating of air temperature in Taipei City.

Figure 3 illustrates the curves of the average air temperature with the amount of A-type evaporation in Taipei. We observe that an aging building induces a change in the thermal conductivity of the concrete structure. The amount of A-type evaporation exhibits a V-shape pattern, and according to the literature on the cycle of thermal conductivity of concrete structure being 20 years, the historical data of Taipei City also meet this claim. When the number of new buildings decreases, the atmospheric temperature increases the thermal conductivity of a new building starts a decreasing stage from 1 to 10 years and following an increment stage at the 11-20 years. A building built in 1998 had the lowest thermal conductivity in 2008, and it recovered to its original thermal conductivity in 2018. This fact has an evidence in Taipei city.

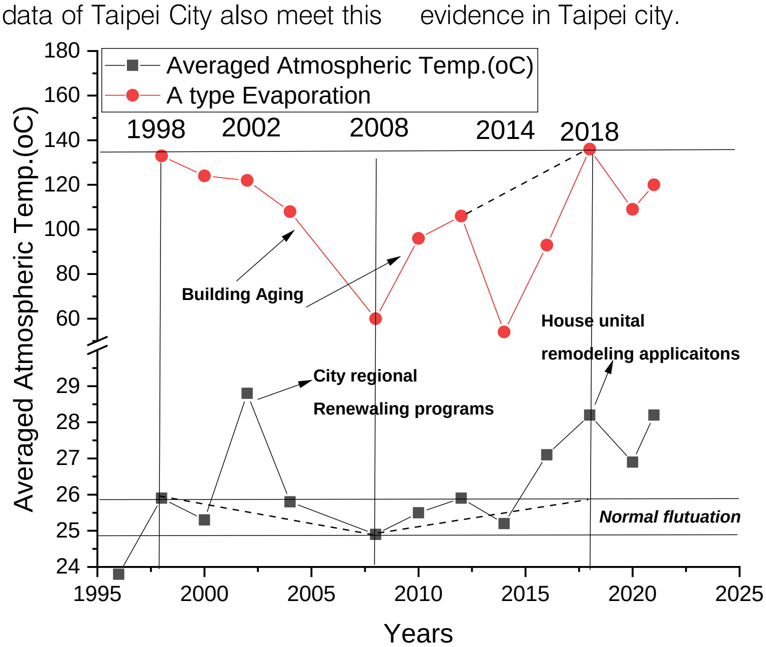


Figure 3: Average Atmospheric Temperature with Amount of A-type Evaporation in Taipei City for 1998-2021.

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The heat transportation from buildings to soil is therefore confirmed, and the air temperature also has a V-shape background curve from 1998 to 2018 in Fig. 3. There are two peaks of temperatures observed between 2000-2004 and 2014-2020. Those two peaks can be attributed to the human heat source of building remodeling. Figure 4 presents the licenses of total floor area usage issued for new buildings. From 1998 to 2008, the license-issued of total floor area usage for new buildings was constant every year, but decrease between 2008-2017. There was a fast growth in the number of old house remodeling in 2016 (Fig. 5), bringing a sharp uptick in atmospheric temperature in Taipei City for 2002 and 2016. Newly modeled buildings are almost covered with thermal-isolation bricks on the exterior wall, causing solar irradiation to potentially accumulate in the atmosphere as potential heat for evaporated water. We call this surface heat source instead of human heat source through a proportional process shown in Scheme 1.

From the data of Fig. 4 and Fig. 5, we observe that remodeling by the public sector was high in 2002, while private sector remodeling was high in 2018. Comparing the data of A-type evaporation, the remodeling in 2002 did not affect evaporation, meaning that the style of remodeling was to renew the exterior wall of buildings. The remodeling style in 2018 was to re-build the whole building and use underground water. Whatever engineering technique is used, a remodeled building must have a relatively higher strength of surface heat during the stage of remodeling. From the results of Fig. 5, we see that limiting 50 cases per year for remodeling is the threshold to keep the atmospheric temperature at 26°C with a normal fluctuation range of 1°C.

Figure 6 compares the remodeling number of buildings and air temperature in Taipei City from 1998 to 2021. The infrastructure in Taipei focused on roads from 1950 to 1970. Taipei City government's national housing started in 1970. From 1999 to 2003, building remodeling focused on so-called military villages. In 2016, the central government announced to build 200,000 units of social rented housing. The highest number of these units are in Taipei City at around 12,600. Therefore, we can make sure that the two peak growth periods in remodeling in 2000-2003 and 2017-2019 are the remodeling of old buildings for social housing in Taipei City and remodeling of military villages for new buildings, respectively. In conclusion, the remodeling number driven by the private sector is the real driving force and has a stepwise growth EKC pattern.

Even if the only maximum annual air temperature is for the EKC pattern, the whole average air temperature also possesses an EKC property. Still, the pattern is modified by the amount of A-type evaporation and the remodeling number driven by the public sector and being M-type. The M-type is also an EKC pattern. If the EKC is a long-term trend to identify environmental concerns, then the air temperature might not be a strongly recognized relative issue. People understand the heat-island effect is caused by civil development, but people still intend to live in a city for a better job and education. To address the living space issue for a crowded city, remodeling the old buildings is the best choice. In Taipei City, the local government has carried out city renewal engineering nearly every 20 years, as mentioned in the previous paragraph.

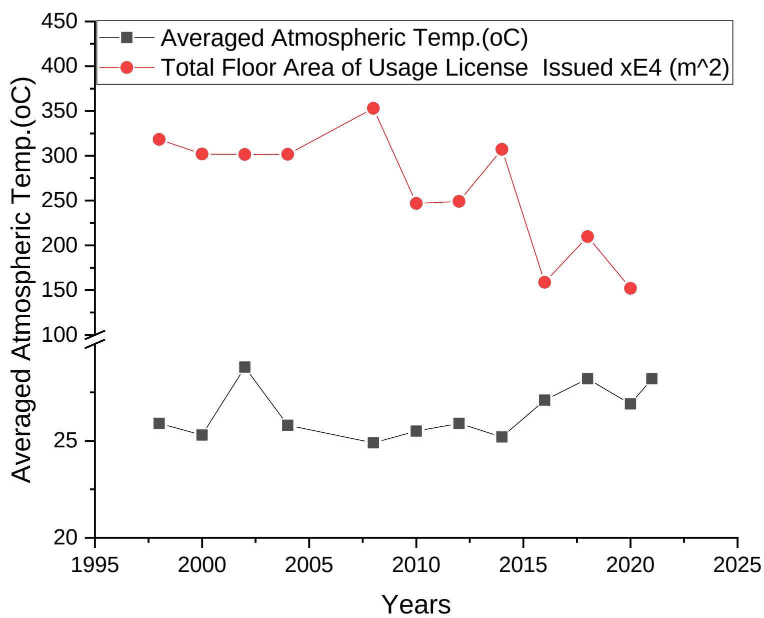

Figure 4: Average Atmospheric Temperature with Licenses for Total Floor Area of Usage Issued for New Buildings in Taipei City for 1998-2021.

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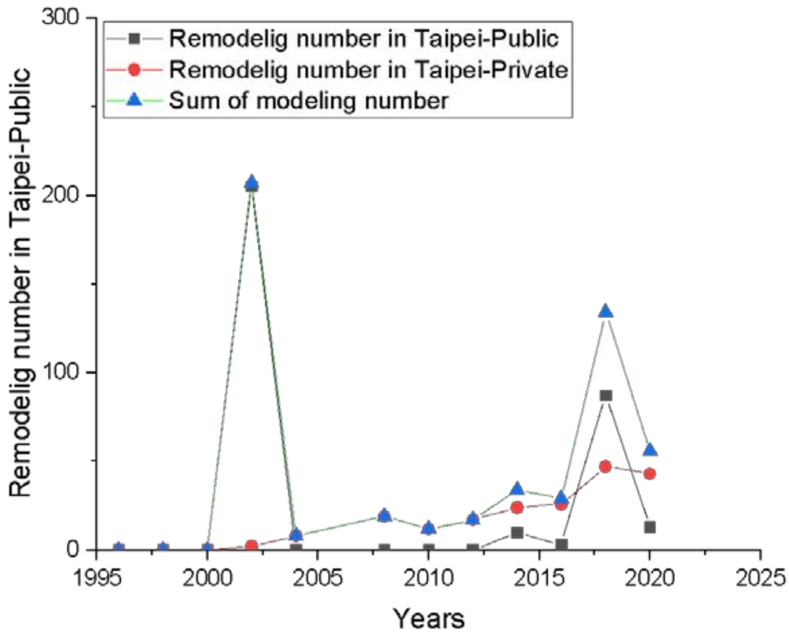

Figure 5: The Number of Remodeled Building in Taipei City for 1998-2021.

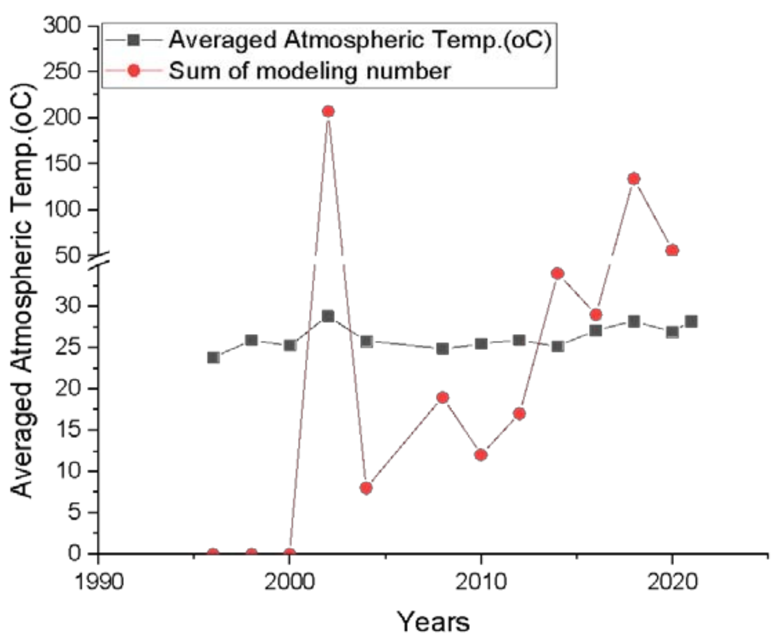

Figure 6: Average Atmospheric Temperature and Number of Remodeled Buildings in Taipei City for 1998-2021.

In Fig. 3, we expected to observe two shorter periods embedded in the EKC baseline to make the M-shape. We now can confirm that those two peaks are both due to the local government policy in Fig. 7. From the results of Fig. 7, the people population number is not a key factor on affecting the maximum annual air temperature. From the results of Fig. 8, the major contributor to the maximum annual air temperature is the number of private remodeled buildings in Taipei City. The slope of CO_2 concentration increment (A1) is different from that of maximum annual air temperature (A2) (Fig. 9), due to the remodeled buildings can be heat sinks for solar irradiation. Although CO_2 is a heat transducer, it is not a sink naturally. From our results, the growth in the baseline of maximum air temperature comes from the amount of remodeling by the private sector. In contrast, the peak increment comes from the amount of remodeling by the public sector. The

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minimum air temperature has a long-term decrease and growth period. Therefore, we can ignore the contribution of the minimum air temperature, which is contributed by the amount of A-type evaporation.

The two peaks from policy demand or remodeling of buildings by the private sector both do not have a long-term effect, but rather a short-term one, due to the building sink can maintain the heat during the day (when the sun is out). Still, at night-time the sank heat must leave the building. If the sinking-leaving upcycle is on a 24-hour time scale, we do not observe the urban heat island effect. Therefore, such upcycle must be on a yearly time scale - that is, for the evaporation of water, the sank heat can leave the buildings only by rain. This is the reason we can observe the normal fluctuation in the average air temperature. However, the amount of A-type evaporation amount is also affected by city development, as more heat sink means less rainwater can be stored as underground water. In the hot season, the heat of a city during the day will not leave quickly.

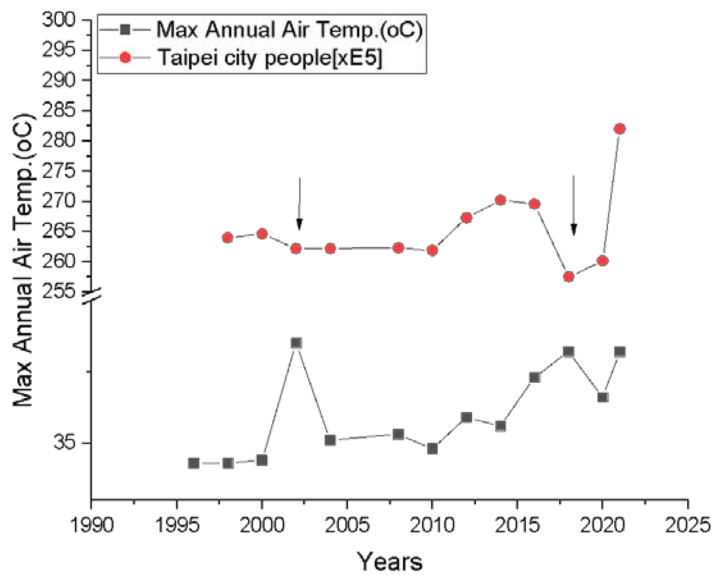

Figure 7: Average Atmospheric Temperature and Number of Remodeled Buildings in Taipei City for 1998-2021.

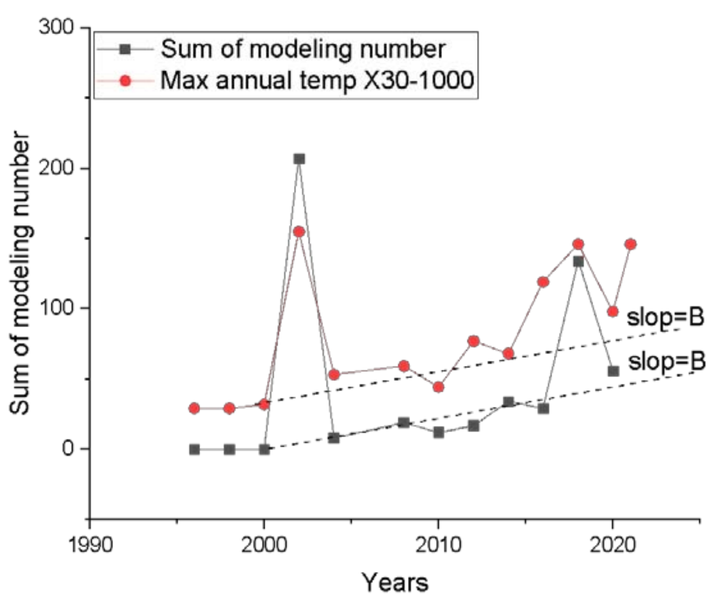

Figure 8: Average Air Temperature and Number of Remodeled Buildings in Taipei City for 1998-2021.

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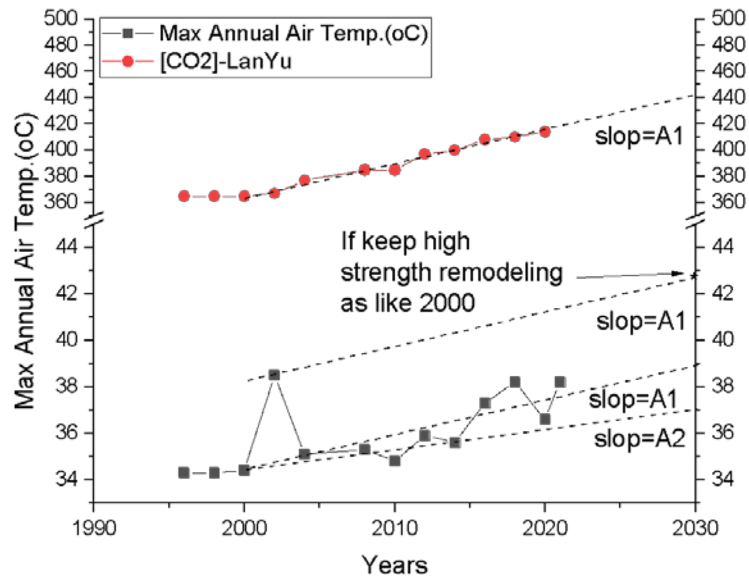

Figure 9: Maximum Outdoor Air Temperature and CO_2 Concentration in Taipei City for 1998-2021.

Figures 9 to 11 show that the amount of rain contributes directly to the A-type evaporation amount, and therefore the upcycle is related to this change. The rain amount is a macro-scale issue and is over the aim of this paper. We can attribute the dominated factor on affecting the A-type evaporation amount is the rain accumulation. The amount of the former impacts the upcycle of the sank heat. It means when there is less sank heat, there is less A type evaporation amount needed.

When the CO_2 concentration is fixed through maintaining the energy structure of a country, the urbane heat island effect could be addressed by adjusting the re-modeling timing of the second stage (i.e., 2008-2018 in Fig. 3) for A-type evaporation U shape-curve and not in the first stage (i.e.,1998-2008 in Fig. 3. From the data in Fig. 3, we observe that A-type evaporation amount has started to decrease year by year since 2018.

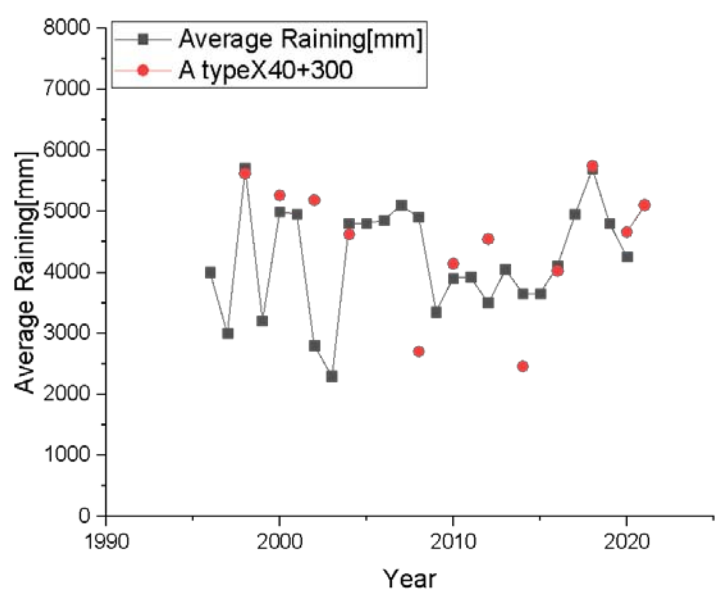

Figure 9: Accumulated Rain Amount and Amount of A-type Evaporation in Taipei City for 1996-2021.

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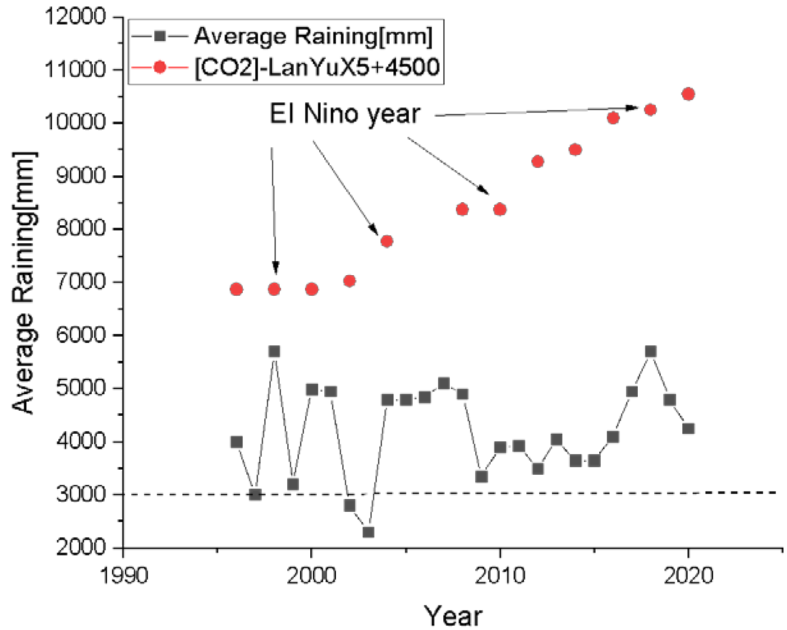

Figure 10: Accumulated Rain Amount and CO_2 Concentration in Taipei City for 1996-2021.

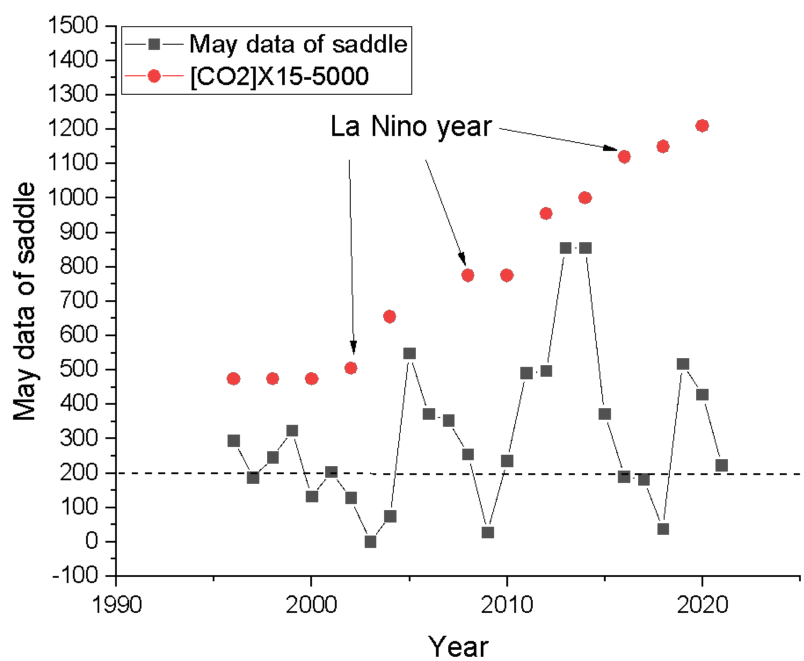

Figure 11: Monthly Rain Amount Data in May in Datunshan Saddle and CO_2 Concentration in Taipei City for 1996-2021.

Global warming means that global annual temperature increases since industrial evolution due to increase CO_2 and other pollutants are emitted and collected in the atmosphere. The urban atmospheric temperature is also raised. However, we cannot exclude the reverse theory - i.e., the urban heat island effect warms the outdoor air temperature. Thus, the urban heat island effect is the symptom of the global warming issue

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at a single city level in Taiwan. A shorter period (~10 years) has been observed in Fig. 2. When we separate the Kuznets infrastructural investment cycle (for example, new buildings) 1998-2021 into two parts, the first period would be located. Figure 12 shows the minimum annual outdoor air temperature with A-type evaporation amount in Taipei City from 1998 to 2021. The results demonstrate that this air temperature is controlled by an A-type evaporation amount with a V-shape Kuznets curve. Figure 13 shows the maximum annual outdoor air temperature with A-type evaporation in Taipei from 1998 to 2021. The results demonstrate that this air temperature is not related to A-type evaporation amount anymore, and the shape of the maximum annual air temperature is controlled by the public housing policy. The public housing policy does not contribute to the minimum annual air temperature in Fig. 12. In Fig. 13, the combined averaging air temperature is calculated from the minimum and maximum. The results show those two data (observed and combined averaging) perfectly fit each other.

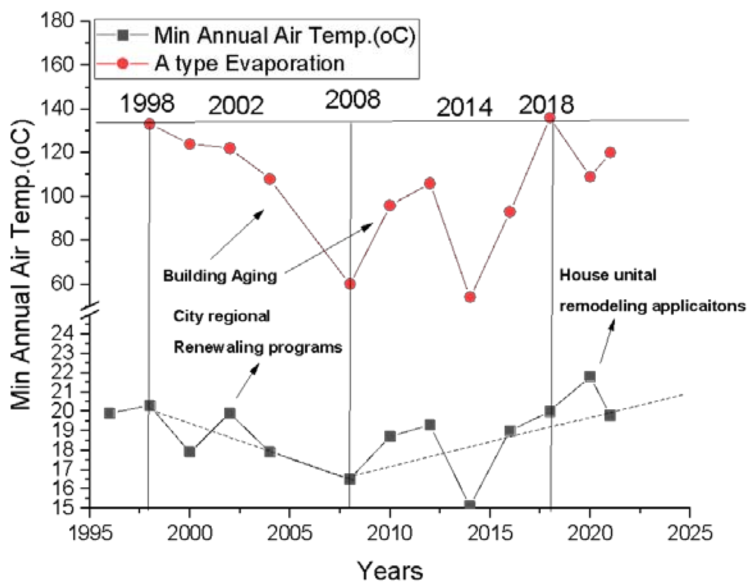

Figure 12: Minimum Annual Outdoor Air Temperature and A-type Evaporation Amount in Taipei City for 1998-2021.

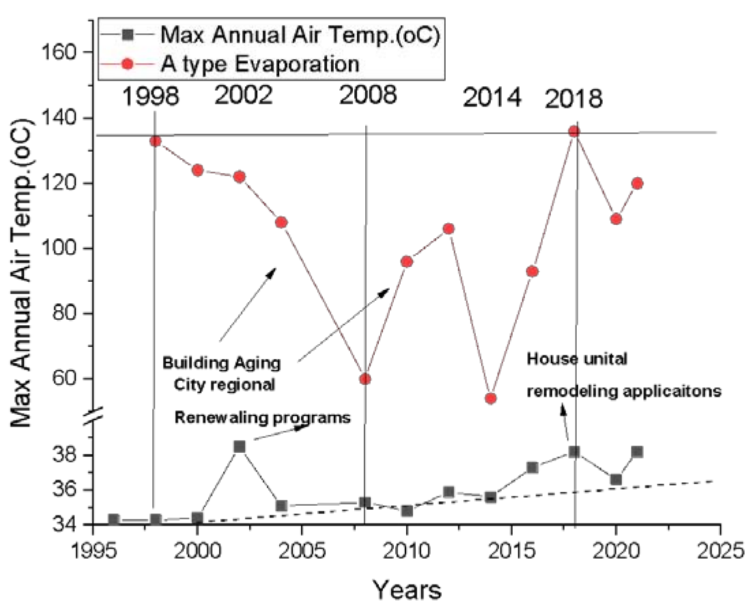

Figure 13: Maximum Outdoor Air Temperature and A-type Evaporation Amount in Taipei City for 1998-2021.

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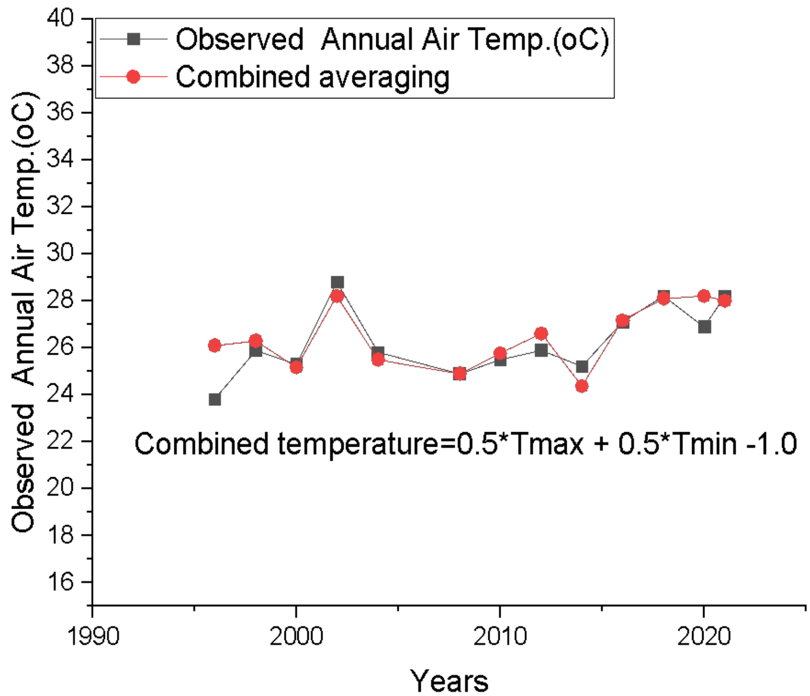

Figure 14: Average Atmospheric Temperature, Maximum Air Temperature, and Minimum Air Temperature in Taipei City for 1998-2021.

IV. Concluding Remarks and Policy Implications

Countries the worldwide have made great efforts to reduce global warming for many years, with many international contracts trying to retard the incremental rate of atmospheric temperature. This present paper aims to explain the issue of the growth of atmospheric temperature. From our study, the factors influencing the growth of urban atmospheric temperature are the aging cycle of thermal conductivity inside concrete structures and the remodeling of old buildings in Taipei City, Taiwan, which is the biggest city and the capital city.

In Taiwan, the remodeling of old buildings is usually promoted by the local government policy, and from 2001 to 2020, more than 50% of cases were applied in Taipei City. 36.9% of buildings in Taiwan's capital, Taipei City, are over 40 years old, ranking first among all cities in Taiwan. Even when lacking data for remodeling engineering of old buildings 1998-2009 in Taipei City, the atmospheric temperature incremental rate 2001-2004 is similar to that of 2016-2021. We believe that remodeling should continue to occur, but from news reports in these years, the engineering was usually to prevent the falling of bricks on the exterior walls of old buildings. Thus, the A-type evaporation amount did not change for 2001-2004, due to the engineering using very little water. Conversely, the engineering that took place 2016-2021 consumed more underground water because the remodeling was for re-constructing the whole building.

Maintaining the atmospheric temperature in a big city cannot keep A-type evaporation. This point runs opposite to the currently popular strategy in the civil engineering field that recommends people to own plants and use building materials with high water penetration efficiency. Still, high thermal insulation bricks and painting are also recommended. Our results demonstrate that the surface heat source is the major contributor to atmospheric temperature. Such surface heat is produced from high thermal insulation bricks and painting after the remodeling of old buildings. In Taiwan, people use high thermal insulation bricks and painting to save the cooling electric power of those constructions, which increases the atmospheric temperature.

Moreover, CO_2 reduces the reflection efficiency of solar irradiation to outer space. One might ponder that CO_2 can be kept at the level of 2010 until 2021, then the temperature should be lower. However, the CO_2 concentration is almost similar for all cities in Taiwan, but only Taipei City has the highest urban heat island effect. It means that the dominated point is to keep the thermal transportation of the building to the soil rather than to isolate the building from the environment. The thermal balance of a building should be re-designed, and the interaction between the environment must be

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considered. The policy can be set up to advise this to reduce the urban heat island effect in the capital city.

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