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Heat vs. Health: Home Office under a Changing Climate

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Abstract: Stressors are especially widespread in urban agglomerations. Common themes of built environment interventions that support health and well-being are blue and green infrastructure, indoor and outdoor air quality, thermal comfort, access to natural lighting, and acoustics. Given the current megatrends of increasing summer temperatures and the high popularity of home offices, we aimed at modeling thermal comfort changes of people working at home in three Austrian cities (Vienna, Innsbruck, and Graz) during the next decades until 2090. We present findings based on (I) an inter-disciplinary literature search and (II) indoor and outdoor climate simulations for actual and future climate scenarios. Based on the results, we discuss the potential impacts for work and human health and well-being, and we suggest a framework for the home office in "post-COVID-19 Austria" that integrates social, ecological, and economic aspects. The results of our study indicate that, in future climate scenarios, overheating of the interior can no longer be prevented without active cooling measures and nature-based solutions. Recommendations on the adjustment of behavior under climate change, including greening, adequate ventilation, and cooling techniques, are thus urgently needed for employees who are working from home in order to maintain physical and mental health and wellbeing.

Keywords: home work; climate simulations; Austria; built environment; urban heat island effect; health

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Citation: Schaffernicht, S.K.; Türk, A.; Kogler, M.; Berger, A.; Scharf, B.; Clementschitsch, L.; Hammer, R.; Holzer, P.; Formayer, H.; König, B.; et al. Heat vs. Health: Home Office under a Changing Climate. *Sustainability* **2023**, *15*, 7333. https://doi.org/10.3390/su15097333

Academic Editor: Aliakbar Kamari

Received: 8 February 2023
Revised: 7 April 2023
Accepted: 25 April 2023
Published: 28 April 2023

1. Introduction

The COVID-19-pandemic and the current economic situation has impacted mental health for many people, as stress, anxiety, and depression have increased during recent years [1]. Social and environmental stressors are especially widespread in urban agglomerations, where the largest part of the population worldwide lives and works. These densely populated places are disproportionally affected by longer, more intense, and more frequent heat waves due to climate change [2], which have significant negative impacts on human health and well-being, as well as on work performance. The urban heat island effect—a microclimatic phenomenon that causes more heat stress in cities than in rural areas [3]—has especially negative effects on human health [4] in all climatic zones of the world [5].

Urbanization and the associated anthropogenic factors, such as increasing soil sealing and the use of dark heat-absorbing surfaces such as asphalt and concrete, as well as the absence of vegetation in urban landscapes, contribute significantly to this problem [2]. Smaller settlements are as affected by the phenomenon as larger cities [6,7]. So far, scientists have confirmed that the effect is appearing in over 400 cities [8,9].

Generally, climate change has direct effects through storms, droughts, floods, and heat waves, but it also affects water and air quality, land use, and ecological change, including mass mortality events, shifting species distributions, altered phenology, and indirectly changing ecosystem productivity [10]. Multifold aspects, such as age, gender, health, socioeconomic status, social capital, public health infrastructure, mobility, and conflict status, impact the levels of vulnerability of urban dwellers [5]. Health risks are thus unequally distributed across the strata of the population [11]. The unequal distribution of these risks and potential mitigating factors—e.g., the existence of green and blue infrastructure such as parks, fields, sports facilities, gardens, trees, green facades, pools, or ponds—also contribute to health inequities [12].

The socioeconomically vulnerable, chronically ill people, persons with mental illness, elderly people, pregnant women, women in childbirth, children, people with restricted mobility, people with learning disabilities, homeless people, migrants, refugees, emergency workers, environmental researchers, and therapists are often more affected by the consequences of climate change than the rest of the population [10,13,14]. Among those inhabitants, older people [15], people who already have diseases [16], socially isolated people [17], and people who live in attic apartments and in nursing homes [18,19] are those most affected by heat waves.

The effects of heat on general mortality [20] and, particularly, on cardiovascular casualty [21] are demonstrated by various scientific studies. Among the less anticipated effects of climate change and the related increase in natural disasters are the negative impacts on mental health [10,22], which has received increasing scientific attention over the past decade. According to the Special Report Health, Demography, and Climate Change, elaborated by the Austrian panel for climate change in 2018, health risks and their impacts will increase in Austria as well [23]. There is scientific evidence that urban heat increases mortality due to cardiovascular stress, heat stress, heat strokes, thermal exhaustion, and increased vulnerability. On a local level, the urban heat island effect increases thermal discomfort and cooling demand. Studies found that high outdoor temperatures can contribute to the sick building syndrome—a set of non-specific symptoms experienced by occupants due to time spent in a building with poor indoor air quality [24,25]. Increased temperatures in cities cause further health risks, given their impact on urban groundwater quality and local food production capacities [26].

During the last decade, working at least part-time from a home office has been feasible for many office-based jobs [27]. It has been especially popular in the start-up scene and the digital nomad community. However, it has been heavily discussed among employers whether the home office was reasonable with regard to workload management and employee performance. If adequate framework conditions are put into practice, employees who work remotely perceive less stress because they do not have to commute to work and see the associated time savings as positive. Thus, they experience a better work–life balance [28]. Other advantages are the possibility of a more health-conscious lifestyle, for example, with regard to sports and nutrition. Nevertheless, the home office also has disadvantages, e.g., fewer social contacts with colleagues, problems separating family and working life [28], or the undermining of existing restorative functions of the home [29].

With the lockdowns and curfews associated with the COVID-19 pandemic, the numbers of employees working from home sharply increased worldwide [30]. In Austria, for example, 17.7% of the employed population, which was, on average, about 4,440,000 people aged 15, worked from home during the last quarter of the year 2021, with little difference in the proportion of men and women [31]. Furthermore, home office work was performed more often by people with higher levels of education and professional qualification. The industries with the highest proportions of home office workers included information, communication, financial, and insurance services. In terms of climate change mitigation, there is evidence that working from home can decrease CO_2 emissions, even if new equipment is bought and if both offices and homes need to be heated and lighted [32]. As this working style is a global megatrend and will probably accompany us into the future, it is necessary to think about methods that are advantageous from the perspective of social sustainability, with a consideration of health inequities as well. To promote social sustainability, it is important to consider the impact of the home office on workers. This includes providing information and resources to help people recognize the symptoms of illness, mental and physical, associated with the home office and develop strategies to reduce them. For example, despite an increase in the numbers of people working from home, there is still insufficient protection from the perspective of occupational safety in regard to ergonomic working conditions [33].

Researchers found that 45% of the workforce in the United States noticed a decrease in their mental health due to feelings of loneliness and isolation while working from home [34]. One of the implications of the heat island effect is that working from home during heat waves may become increasingly uncomfortable, which could have impacts on, e.g., well-being, health inequities, and work performance. Although the same principles that apply to designing healthy office spaces also apply to designing home workspaces, stress and mood disorders have increased during the COVID-19 pandemic [35] given the rising numbers of home offices. This might aggravate already existing inequities.

Not only the routines of the pandemic, but also the climate and biodiversity crisis have negatively affected human health, in general, and, especially, mental health [22]. Research has proved, for example, that mental health and species diversity are positively related: Street tree planting in residential areas of cities may be a nature-based solution to reduce the risk of depression, with the added benefits of also addressing climate change and biodiversity loss [36,37]. Up until now, aspects related to climate change and biodiversity loss are often lacking in public and scientific debates of urban planners and health professionals. Therefore, our study aims at modeling thermal comfort changes of people working at home in three Austrian cities (Vienna, Innsbruck, and Graz) during the next decades, until 2080, on the basis of outdoor and indoor climate data. Based on the results, we discuss the potential impacts for decent work (Sustainable Development Goal [SDG] 8) and human health and well-being (SDG 3), and we suggest a framework for the home office in "post-COVID-19 Austria" that integrates social, ecological, and economic aspects.

2. Methods

The results presented in this article are based on (I) a literature search and (II) indoor and outdoor climate simulations. The methodological approaches are described in the following subchapters.

2.1. Literature Search

Our study aims to investigate the impact of two megatrends, i.e., increasing summer temperatures and the high popularity of the home office, on the thermal comfort of people working from home in the three Austrian cities of Vienna, Innsbruck, and Graz until the year 2090. The conceptual framework of the study involves identifying the factors that influence thermal comfort, such as indoor and outdoor temperature, humidity, air quality, and clothing insulation. A previously published Grounded Theory, Action, and Evaluation Research Study [38] analyzed how inclusion of people with disabilities in the general work market can be successful. We adapted the framework developed therein to the topic of the home office through including further literature on the topics of mental health and well-being, morbidity and mortality in the built environment, climate change and biodiversity loss, environmental quality, and sustainability, and we complemented it, in an interdisciplinary way, with indoor and outdoor climate simulations. The search engines Google Scholar and PubMed were used, and only literature in the English language published in international peer-reviewed studies was thereby considered.

2.2. Climate Simulations

As mentioned above, Austria was the region of interest in this study. Climate simulations request accurate and representative driving parameters to provide valid results.

Therefore, climate data were chosen that cover all necessary meteorological variables and different conditions of densely populated areas in Austria in order to allow for the capture of historical development as well as of future climate scenarios in the temporal resolution and under consideration of different climate scenarios. Due to the high computational requirements of individual simulations, a set of representative cities and climate scenarios for Austria were chosen, and only the smallest possible number of episodes, which was five days, was calculated. To identify representative heat wave situations, historical weather data and future climate scenarios were analyzed. The simulations were carried out using microclimate simulation software. The methodology is described in detail in the following subchapters.

2.2.1. Selection of Locations

Three different locations were selected. First, we chose Vienna—the capital of Austria—with 1,931,593 inhabitants in 2020 [39]. Vienna is characterized by a strong urban heat island effect. However, Vienna is also a characteristic example for cities located in well ventilated lowlands, in this case represented by the Danube valley. For the other two locations, we selected one to be representative of an inner-alpine valley, characterized by a much stronger diurnal variation in temperature, and the other to be a representative of a large alpine basin often having very low wind speeds. Innsbruck, the capital of Tyrol, with 132,961 inhabitants, was selected for the valley location, and Graz, the capital of Styria, with 291,072 inhabitants, was selected for the basin location [40].

2.2.2. Definition of Heat Waves and Climate Scenarios

To capture possible accumulating effects during heat waves, episodes with a total length of five days were investigated. Furthermore, not the most extreme heat waves were investigated, but events that have to be expected repeatedly and, therefore, for which an adaptation is necessary. Therefore, the five-day average of the daily maximum temperature defined the heat wave intensity, and we selected events with a two-year probability of recurrence. Since the period 1981–2000 is, by consensus, the reference for temperature limits in Austria, we determined the probability of recurrence for this period. For consistency reasons, a period of 20 years was fixed for the other time periods as follows. In addition to 1981–2000, we used the period 2001–2020 to quantify the climate change that has already occurred, as well as the periods 2041–2060 (abbreviated as 2050) for mid-century and 2070–2090 (abbreviated as 2080) for the end of the century.

The calculation of the heat wave temperatures, as well as the probability of recurrence, was based on the inner-city meteorological statistics of the Austrian weather service ZAMG (Zentralanstalt für Meteorologie und Geodynamik, the Central Institute for Meteorology and Geodynamics) at the three locations [41]. We used the Austrian bias corrected and localized climate scenario ensembles ÖKS15 (Österreichische Klimaszenarien 2015) [42] to determine the climate change signal. For this purpose, we calculated the maximum five-day heat wave for each site and climate model and each year, and then the temperature change related to the period 2001–2020 for the two future periods.

Figure 1 shows the results for Vienna. Until the middle of the century, we did not detect large differences in the scenarios, but we detected very large differences at the end of the century related to the underlying emission scenario. We calculated two different climate scenarios and defined a low impact scenario, representing the development until the middle of the century, or for the compliance with the Paris Climate Protection Agreement (RPC 2.6), and a high impact scenario, covering the possible range of the development until the end of the century. For the low scenario, an average of the ensemble means RCP 4.5 and RCP 8.5, at mid-century, and RCP 2.6, at the end of the century, was calculated (Figure 1, black line). For the high scenario, we used the 75th percentile of RCP 8.5 at the end of the century (Figure 1, green line). This thus represents a plausible worst-case scenario.

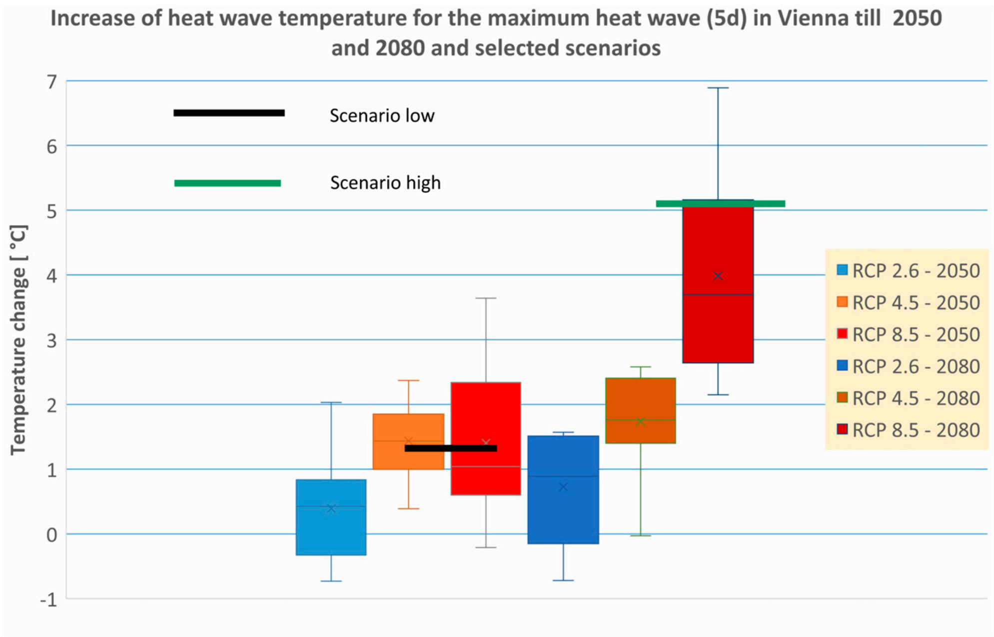

Figure 1. Climate change signals related to the period 2001–2020 for maximum 5-day heat waves in Vienna. The selected scenario low corresponds to the mean development under RCP 4.5 and RCP 8.5 until the middle of the 21st century, and the scenario high corresponds to the 75th percentile of RCP 8.5 at the end of the 21st century.

2.2.3. Data Preparation for the Modeling

For the model applications, half-hourly meteorological data for the variables air temperature, humidity, global radiation, direct and diffuse radiation, wind speed, wind direction, and precipitation are required. The typical different diurnal cycles of the three locations, as well as the physical correlations between the different variables, are decisive for the interpretation of the results. The episodes for the future periods were not taken from the ÖKS 15 climate scenarios; historical heat waves, which corresponded to the corresponding mean value of the temperature maximum in the future periods, were used. Thus, the site-specific characteristics are preserved. Very suitable episodes could also be found; only at two locations did the temperature have to be raised by a few tenths of a degree at some hours for the high scenario.

Based on the direct calculation from observational data for the two historical periods and the addition of the climate change signal determined from the ensemble values of the ÖKS15 scenarios, the mean temperatures of the investigated heat waves were determined (Table 1). During the observation period, heat wave temperatures increased markedly. Since the definition is based on the daily maximum temperature, this is about the same in Innsbruck as in Vienna. In Graz, it is about 1.5 degrees lower. This is due to the fact that the Inn valley, where Innsbruck is situated, heats up very strongly during the day and thus reaches a daily temperature maximum similar to Vienna, whose elevation is about 385 m lower than that of Innsbruck.

Table 1. Mean temperature of five-day heat waves with a return probability of two years.

Location	Period (Calendar Year)		Scenarios (°C)	
	1981–2000	2002–2020	Scenario Low	Scenario High
Graz	30.4	32.3	33.6	36.7
Innsbruck	31.2	33.9	35.6	37.9
Vienna	31.7	33.9	35.4	37.0

2.3. Outdoor Climate Simulations

The concept of urban standard typologies (UST) served as the basis for the analysis of the outdoor climate assessment [43]. It was developed to represent recurring, typical city structures of different metropolises in a standardized and comparable way based on the cities of Santiago de Chile, London, Vienna, Cairo, and Hong Kong. Within the project GREEN.RESILIENT.CITY, these USTs were further developed and adapted to typical structures of Vienna [44]. For this article, the most relevant UST categories for Austrian state capitals were selected. The identified USTs were combined into a large model consisting of 9 USTs in a 3 × 3 grid and integrated into the city centers of Vienna, Graz, and Innsbruck (total model approximately 11 ha).

The software greenpass for climate-resilient urban planning and design was used to assess the outdoor climate during the heatwaves [45]. Greenpass analyzes, optimizes, and certifies buildings and the impact of vegetation regarding climate resilience, and it is based on the microclimate simulation model ENVI-met. ENVI-met calculates radiation fluxes from buildings and vegetation, plant physiological processes, surface temperatures of facades and roofs considering the material, water and heat exchange in the soil, and biometeorological variables [46]. For the outdoor climate simulations, the horizontal resolution was defined as 2 × 2 m, the vertical resolution as 3 m, and the results are resolved hourly. The standard materials of buildings and greenings of the greenpass database were used as simulation settings. As a boundary condition, the method "Full Forcing" was chosen, i.e., every half hour, weather data is copied as a 1D model to the boundary of the model area.

2.4. Indoor Climate Simulations

The simulations of the indoor climate were conducted for one new and two existing highly representative building types. Those were identified in the analyses of the UST. To analyze the indoor climate, critically located (south-west oriented) zones, one on the first floor and one on the top floor, in three different building types were simulated. All U-values of the existing buildings were drawn from default values of the Austrian Institute of Construction Engineering (OIB) guideline 6 2015. Both existing buildings were implemented with an unheated attic. The new building was implemented with a flat roof. The U-values of the new building are drawn from an executed energy performance certificate calculation and should mirror ambitious new buildings. It was assumed that the existing multifamily home is a so-called "Gründerzeit" building erected around 1900. The single-family home was built around 1945, and the new multifamily home dates from 2020.

The exemplarily selected building models were first brought into a thermally stable state by means of several simulation runs of identical recurring diurnal cycles. Subsequently, the building models were subjected to a dynamic building simulation under the conditions of the five-day heat wave modeled for RCP4.5 for 2050, as well as RCP8.5 for 2080. The simulation software used was IDA ICE Version 4.8, which considers the transient heat flow and storage effects in the building components, as well as solar and thermal radiation, in the time-stepping procedure.

2.4.1. Simulation Model

We assumed that the existing buildings will be renovated in 2050, and no renovation was considered for the new built houses during the period in question. The renovation measures were chosen with reference to a standardized renovation concept, which was developed by the market-leading property developer from broad implementation experience. As a result of the renovation, the heating load of the buildings falls below 35 W/m^2, almost irrespective on the structural qualities of the initial stock. The applied renovation measures were:

- 16 cm insulation (λ = 0.036 W/(m.K)) on the external walls
- 30 cm insulation (λ = 0.036 W/(m.K)) on the top ceiling
- 18 cm insulation (λ = 0.036 W/(m.K)) on the bottom floor

- Renovated double windows (U-value glass: 1.0 W/(m^2.K), g-value: 0.58, U-value frame: 1.4 W/(m^2.K), frame share: 30%). In comparison, the unrenovated windows have a U-value glass: 2.5 W/(m^2.K), g-value: 0.67, U-value frame: 3.0 W/(m^2.K), frame share: 30%
- Exterior sunscreen (g_{tot} = 0.1 according to ÖNORM B 8110-6-1: 2019-01 Table 18)

2.4.2. Boundary Simulation Conditions

The boundary simulation conditions were split into independent and dependent of the type of use. The following are the simulation conditions that are independent from the type of use. The effective area was 15 m^2 (3 × 5 m, width × length) with a room height of 3.4 m in the existing buildings and 2.5 m in the new buildings. The window share was 19% in the existing multifamily home and 30% in the existing single-family home and the new multifamily home. In relation to night ventilation, one window was opened from 7 a.m. to 8 a.m. and tilted from 10 p.m. to 7 a.m. The rest of the time, the window was closed. The sunshade was controlled via a schedule. From 8 a.m. to 4 p.m., the sunshade was drawn completely; from 4 p.m. to 8 p.m., the sunshade was drawn to the half; and from 8 p.m. to 8 a.m., the sunshade was not drawn. The dependent applied boundary simulation conditions are described in Table 2.

Table 2. Dependent boundary simulation conditions.

Conditions	Residential	Justification	Home Office	Justification
Internal gains	⌀4.5 W/m^2 from devices	According to ÖNORM B 8110-3 2020 Table 2 and Table 3	⌀6.7 W/m^2 from devices	For change in internal gains due to equipment, the internal gains according to ÖNORM B 8110-3 2020 for offices were added to those of residential use from 8 a.m. to 4 p.m.
	⌀2.9 W/m^2 from humans		⌀3.8 W/m^2 from humans	
Hygienic air exchange rate	⌀1.1 m^3/(m^{2}h)	According to ÖNORM B 8110-3 2020 Table 4	⌀2.0 m^3/(m^{2}h)	According to ÖNORM B 8110-3 2020 Table 4

3. Results

For this article, we adapted the grounded theory coding paradigm developed in a previous study on inclusion of people with disabilities in the context of work under climate change and biodiversity loss [47]. We assumed that the rights of all strata of the population [48] are potentially affected in the built environment, in addition to children and adolescents, especially in what concerns employment, study, health, and well-being. These aspects were summarized in a framework on climate change, biodiversity loss, and health in the context of the home office). Causal conditions (the pandemic) and phenomena (morbidity and mortality) have been already described in the introduction of this article. The next subchapter presents the context of the study (mental health) with a special emphasis on the situation in Austria.

3.1. Context: Mental Health

Mental health and mental illnesses can be defined in various ways. The chosen definition is—among others—always influenced by social and cultural norms. There are different medical and psychotherapeutic models that partly differ, to a great extent, from each other [22]. The World Health Organization (WHO) claims that mental health is not only about the state of individual well-being but about the well-being of society as a whole. According to a scientific study, there are fewer risks of mental health issues in countries with higher levels of general well-being.

Mental health and mental well-being do not differ from each other. They turn into mental disorders—characterized by a combination of stressful thoughts, emotions, behaviors, and relationships with other people—as soon as problems for health and well-being occur. In terms of mental illness, negative trends were already observable in Austria before the COVID-19 pandemics: (1) The number of young people aged between 15 and 24 years applying for disability pensions due to mental problems has been growing to a considerable extent [47], (2) sick leave numbers and rehabilitation stays have been growing due to these problems, and (3) psychological well-being has declined recently [49].

3.2. Intervening Conditions I: Climate Change

3.2.1. Evaluations of the Dew Point

In addition to the processing of the meteorological input data for the models, the development of the dew point temperature was also investigated. Extreme dew point events are indicators related to human thermal comfort. In passive cooling systems, floor or ceiling cooling is used, and the temperature is often cooled down to about 20 °C. However, if the humidity is so high that the dew point temperature exceeds 20 °C, condensation and, in extreme cases, mold growth must be expected in such cooling systems.

An analysis of the current situation shows that such humidity values are still very rarely reached, but that they have already increased significantly due to climate change (see Figure 2). In Innsbruck, this was a decennial event in the period 1981–2000, and, in the last 20 years, it has already occurred once a year. In Vienna, the values are much higher, but the wettest place is Graz, where about two such events occur per year. This is quite astonishing, because the heat waves are much cooler there than at the other two locations. Here, the basin location and the low wind speeds seem to prevent the removal of moisture.

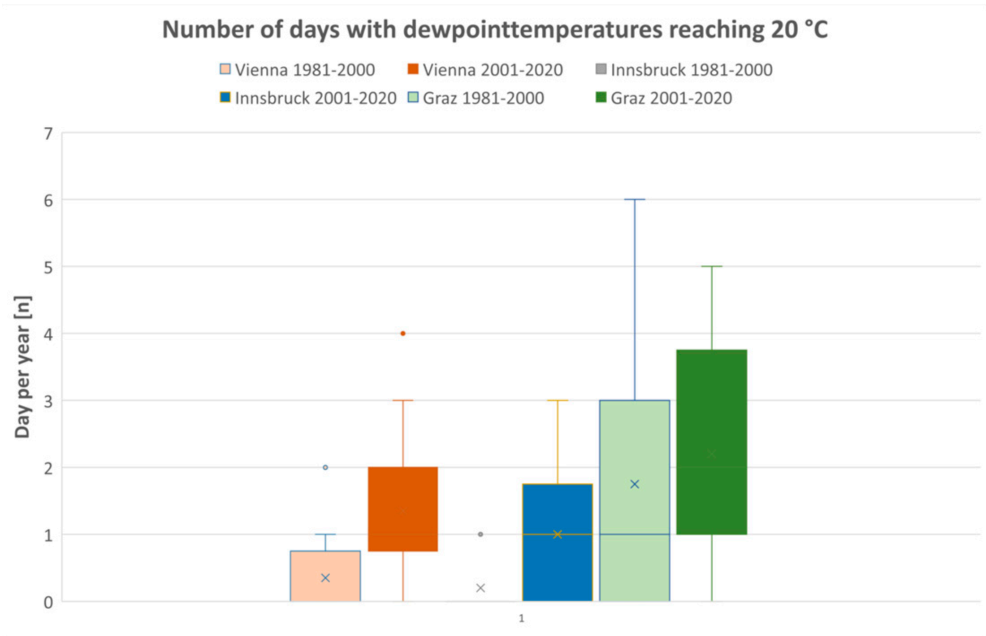

Figure 2. Number of days with dew point temperatures above 20 °C for the period 1981–2000 and 2001–2020 at the three sites.

Looking at the scenarios for Graz, as shown in Figure 3, a massive increase in days with at least 20 °C dew point temperature must be expected due to climate change. In the extreme scenario, this occurs on average more than 16 times per year and, in extreme years, lasts even longer than one month.

3.2.2. Outdoor Thermal Comfort in Different Built Environments

This chapter describes the outdoor climate analyses. Figure 4 provides an overview of the climate input data (dashed line), the simulation output data (solid line), and the mean simulation output data (dotted line) for different time periods during a heatwave in Vienna. The blue lines show the results of the actual climate period, the yellow lines are for the climate scenario RCP4.5 for the year 2050, and the red lines are for RCP8.5 for 2080. This demonstrates the heat island effect due to the influence and heating of the buildings. The simulation output temperature is higher than the input temperature, especially during the day. Except for the first day in the actual period, all nights are tropical nights and, in some nights, the temperature is far above the 20 degrees tropical night mark.

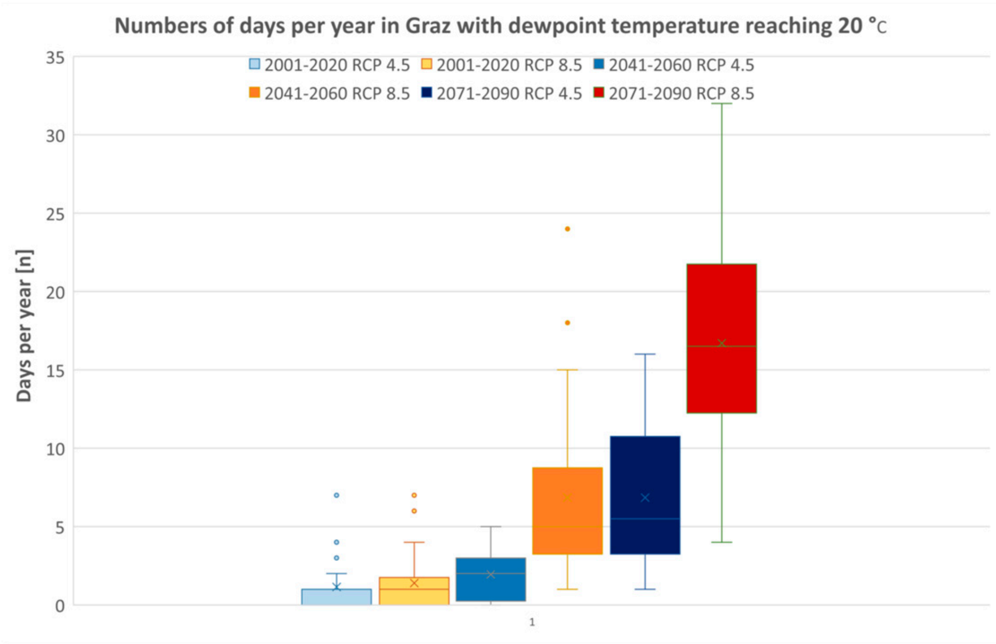

Figure 3. Climate scenarios based on selected models corresponding to the ensemble mean of the emission scenarios RCP 4.5 and 8.5 for Graz.

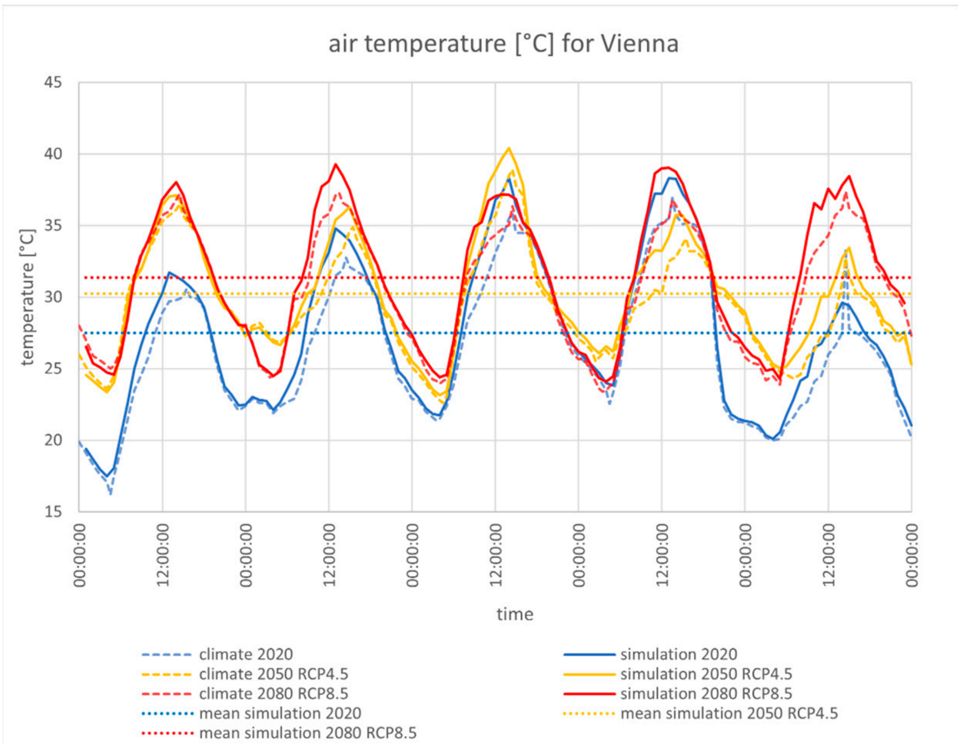

Figure 4. Air temperature [°C] for Vienna for climate input data (dashed line), simulation output data (solid line), and mean simulation output data (dotted line) for actual climate period (blue), RCP4.5 2050 (yellow), RCP8.5 2080 (red).

In order to describe the sojourn quality in the outdoor space, the physiological equivalent temperature (PET) is suitable for this purpose, since the PET calculation takes into account not only the temperature but also the radiation, air humidity, wind, and human physiological parameters [50]. PET is recommended for pedestrian level considerations in urban areas. It is also possible to calculate the PET with lower temperatures, where equivalent indices widely used in the evaluation of outdoor thermal environments, such as standard effective temperature (SET) or universal thermal climate index (UTCI), are not working [51].

Figure 5 shows the PET as a mean value over the heatwave at 3 p.m., with the different building structures in black. The left column describes the actual period, the middle column stands for RCP4.5 2050, and the right is the result of the RCP8.5 2080 heatwave. The first row demonstrates the results of Vienna, the second row of Innsbruck, and the third row of the results of Graz. A PET in the yellow color scale (from 35 °C) indicated a strong heat stress, which applies on all scenarios and cities as minimum thermo-physiological stress. The orange section and above represents extreme heat stress. This means that, on average, during a heat wave, there are no areas that make a comfortable stay possible, assuming typical city structures. As expected, the severity of these circumstances steadily increases in the sequential climate periods. Innsbruck is the most extreme of all cities because it is located in a valley where heat accumulates. Graz, located in a basin, is in the middle, while Vienna scores best, as Vienna is positively influenced by the air ventilation from the west wind.

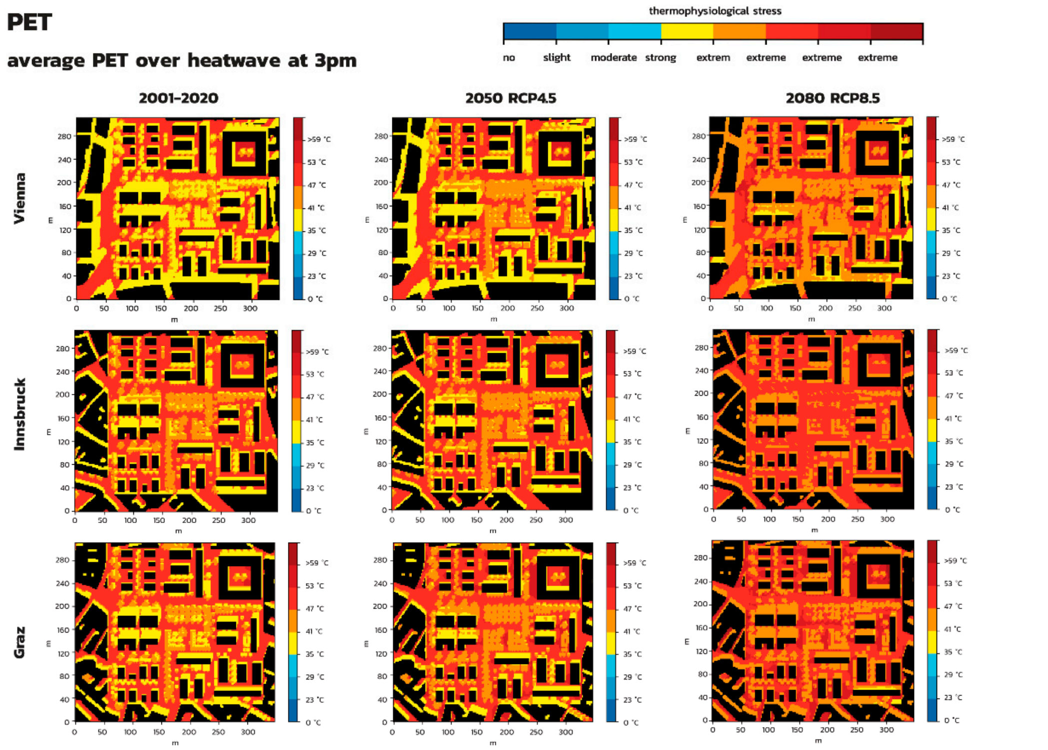

Figure 5. PET [°C] as average over heatwave at 3 p.m. for Vienna (first row), Innsbruck (middle row), and Graz (last row) for actual climate period (first column), RCP4.5 2050 (middle column), RCP8.5 2080 (last column).

3.2.3. Indoor Thermal Comfort in Different Built Environments

The indoor climate simulation simulates different scenarios varying in location, climate period (1981–2000, 2001–2020), and estimated future scenarios (2050 RCP4.5 and 2080 RCP8.5), including various sets of measures to avoid the overheating of indoor spaces. The analysis of the indoor climate simulation is based on the number of hours above certain threshold temperatures. The threshold temperatures are as indicated:

(1) Threshold value for overheating according to the OIB guideline 6 2015

This threshold defines the maximum operative temperature an indoor space may have before it "overheats", according to the old 2015 OIB guideline 6. This threshold is no longer valid.

(2) Threshold value for overheating according to the OIB guideline 6 2019

This threshold defines the maximum operative temperature an indoor space may have before it "overheats", according to the currently valid OIB guideline 6 from 2019. It is necessary to ensure that this threshold is not exceeded in newly built houses. The limit value is calculated as follows: The $T_{NAT,13}$ varies locally and describes a temperature that is exceeded on an average of 13 days per year at a given location. To account for the effects of climate change scenarios, the threshold value is assumed to change. This change in threshold is accounted for by adding the change in mean air temperature during the summer corresponding to various estimated climate scenarios.

(3) Threshold value for overheating according to the WHO

The threshold defines 32 °C during daytime and 24 °C during the night as maximum temperatures that avoid overheating. In this analysis, the threshold of 24 °C during the night is applied.

Due to the relevance of multi-family houses in cities, the existing multi-family house was chosen as a representative example for the three building variants. According to the simulations, only spaces on the top floor will be presented as characteristic zones with the highest risk of overheating. The most relevant and diverse climate change scenarios, 2050 RCP4.5 and 2080 RCP8.5, are displayed. These two scenarios are showcased because of their relevance to the future. Vienna was the province with the highest share of home office use, about 47%, in Austria during 2020 [52]. Therefore, the location of Vienna is used in the result comparison.

Figure 6 shows the top floor of a renovated existing multifamily home within the climate scenario 2050 RCP4.5 with the types of use designated as residential and home office. The comparison of the different types of use indicates that the conditions found in home office use leads to a maximum overheating of indoor spaces of 2.1 °C above the currently valid, but adapted to the climate scenario, OIB threshold of 30.5 °C. In the night hours, the temperatures decrease by means of night ventilation, but they are almost never under the threshold of 27 °C. This is due to high temperatures at night, resulting in a reduced cooling effect by means of night ventilation and the increased internal gains caused by home office use.

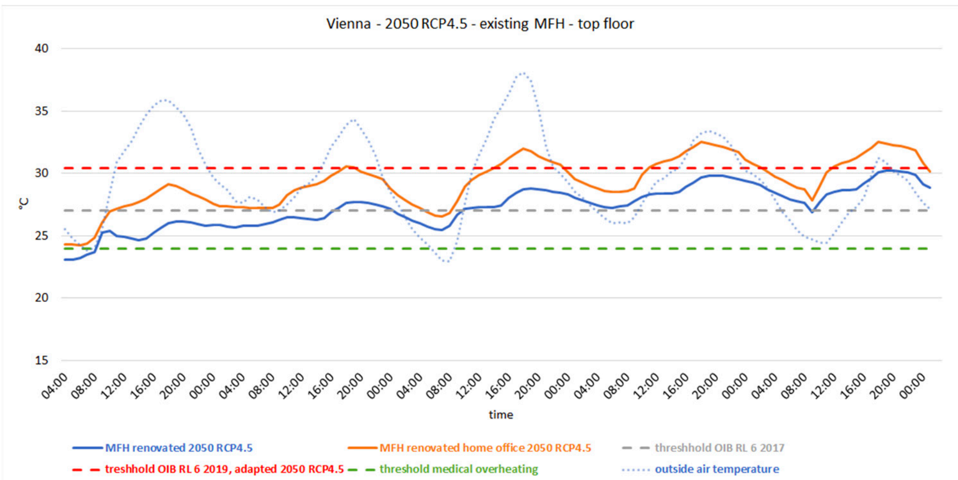

Figure 6. Temperature curve of the top floor in the existing multifamily home in Vienna Inner City 2050 RCP4.5 with home office and residential usage.

Figure 7 describes findings regarding unmet hours. The hours below the recovery temperature of 24 °C and the mean operative temperature in the different types of use comparatively identifies that the home office type of use leads to 40 h above the currently valid, but adapted to the climate scenario, overheating threshold, of which 20 h are during the work hours. Especially in terms of health risk, only one hour is below the medical recovery temperature of 24 °C. The comparison of the different usage types indicates that overheating of the interior can no longer be prevented without active cooling measures.

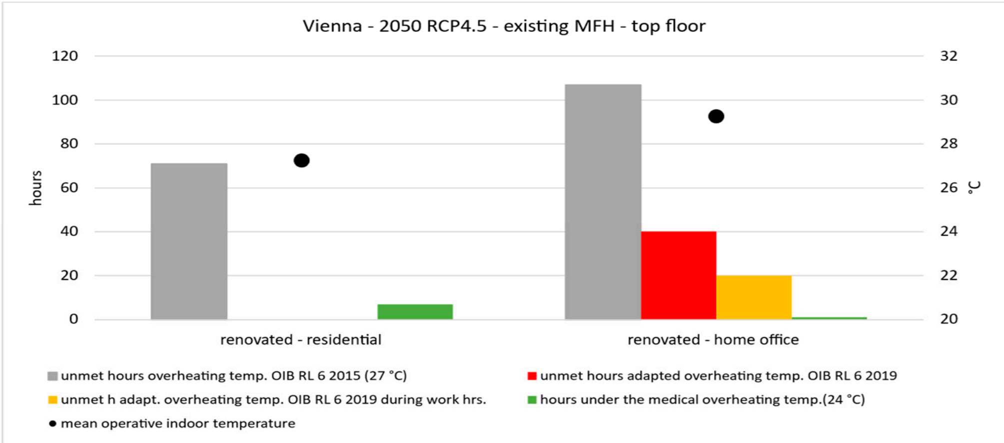

Figure 7. Comparison of the unmet hours, hours under 24 °C, and mean operative temperature during the five-day heatwave in Vienna Inner City in the climate scenario 2050 RCP4.5.

Figure 8 shows the top floor of a renovated existing multifamily home within the climate scenario 2080 RCP8.5 with the residential and home-office types of use. The comparison of the different types of use indicates that the conditions found in home office use leads to a maximum overheating of indoor spaces of 2.7 °C above the currently valid, but adapted to the climate scenario, OIB threshold of 31.0 °C. When being compared to the results of the climate scenario 2050 RCP4.5, the maximum operative temperature is 1.3 °C higher. This is due to the higher outside air temperatures during the day. The night temperatures are with a minimum of 23.9 °C lower than in the climate scenario 2050 RCP4.5, but still not low enough, and especially too few, which leads to a reduced cooling effect by means of night ventilation. Another main reason for the increase in the operative indoor temperature can be traced back to the increased internal gains caused by home office use.

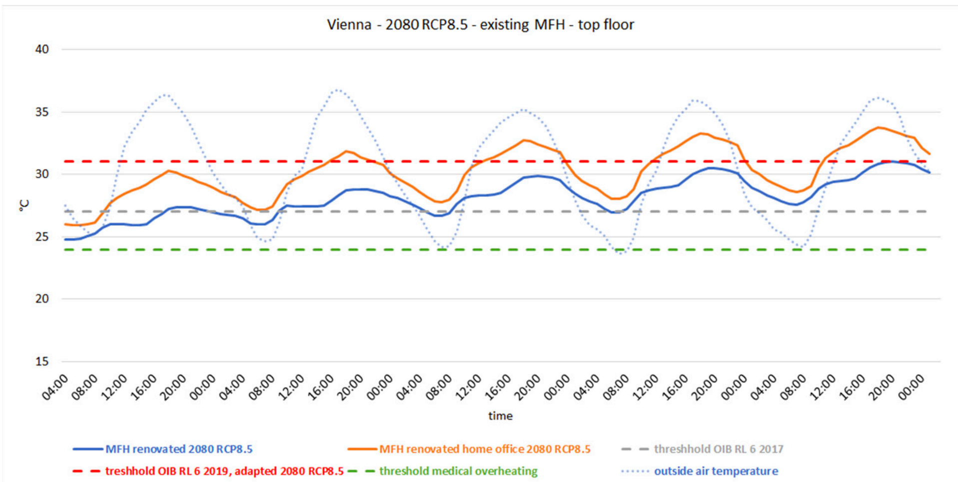

Figure 8. Temperature curve of the top floor in the existing multifamily home in Vienna Inner City 2080 RCP8.5 with home office and residential usage.

In Figure 9, the hours below the recovery temperature of 24 °C and the mean operative temperature at the different types of use comparatively identifies that the home office type of use leads to 45 h above the currently valid, but adapted to the climate scenario, overheating threshold, of which 30 h are during the work hours. Especially in terms of health risk, the temperature never falls below the medical recovery temperature of 24 °C. The comparison of the different usage types indicates that overheating of the interior can no longer be prevented without active cooling measures.

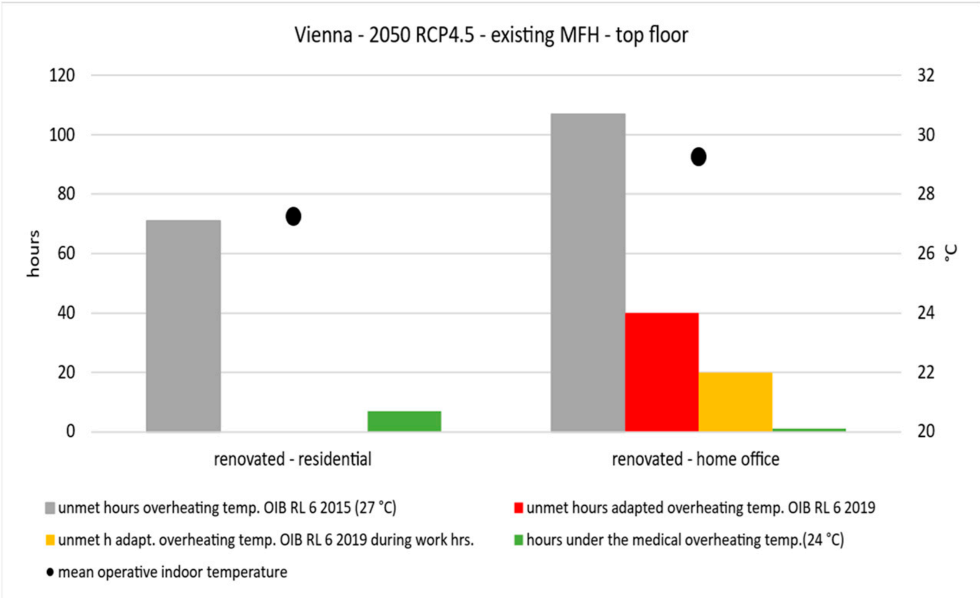

Figure 9. Comparison of the unmet hours, hours under 24 °C, and mean operative temperature during the five-day heatwave in Vienna Inner City in the climate scenario 2080 RCP8.5.

Comparing the two climate scenarios, climate scenario 2080 RCP8.5 results in more unmet hours and higher indoor mean operative temperatures than climate scenario 2050 RCP4.5. The hours under the recovery temperature of 24 °C are also reduced in the climate scenario 2080 RCP8.5. The result of the simulation indicates that, in a home office type of use, the overheating of the interior, with the proposed measures, can no longer be prevented without active cooling measures. In addition, the single-family house features a higher window share than the multifamily house, resulting in a higher risk of overheating, as indicated by our results. Additionally, in the case of home office use, the internal gains exceeded the thresholds. In contrast, the new multi-family home showed results similar to those of the existing multifamily home, likely due to their comparable building physical qualities and identical type of use.

3.2.4. Mental Health Risks

Assuming longer-term impacts of climate change on mental health, as shown in the framework (Figure 10), scientists have started to analyze how adverse climatic conditions can affect well-being and mental health [13]. The first studies confirm that higher temperatures and increased precipitation correlate with a deterioration in mental health [53,54]. Profound emotional responses or disruptions, such as ecological grief, anxiety, feelings of loss, guilt, hopelessness, stress, helplessness, shame, despair, and envy, can be caused or aggravated by climate change [55]. Ecological grief is the feeling that people experience in the face of existing or imminent ecological losses caused by chronic environmental change that can also be observed in our cities due to climate change. Clark [22] mentions anxiety disorders and depression as the main psychological effects, but the author also names post-traumatic stress disorders. The increased mortality is also partly caused by increasing suicide rates [56].

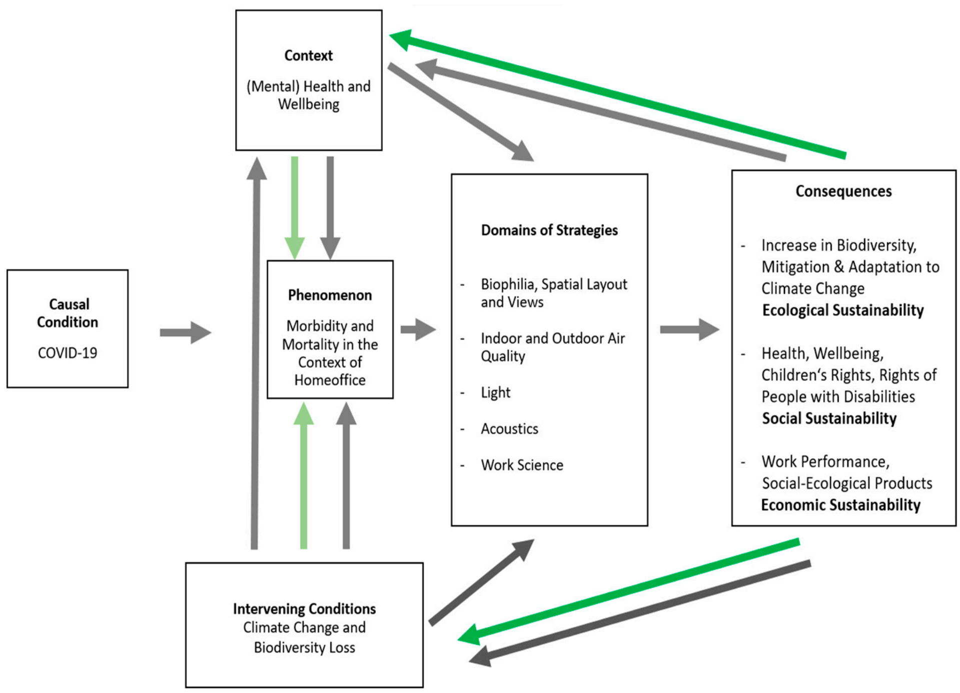

Figure 10. Framework on climate change, biodiversity loss, and health in the context of the home office, adapted from [38].

In the context of climate change, psychotropic drugs can also have a negative effect on a person's homeostasis and lead to damage or even death [22]. Latry et al. [48] stated that antipsychotics, serotoninergics, antihistamines, and anticholinergic drugs can reduce heat elimination via the parasympathetic pathway, that antipsychotics and serotonergic drugs could directly induce hyperthermia, and that the pharmacokinetics of some drugs, such as lithium or antiepileptic drugs, could be altered by dehydration.

Various scientists [13,22] argue that the health system is required to act with regard to the effects of climate change; prevention, intervention, and recovery measures are urgently needed. Berry [13] proposed an analytical framework for the relationship between mental disorders and the health implications of climate change. She named direct (higher frequency, intensity, and duration of climate related disasters, including extreme heat exposure) and indirect (affecting physical health through heat stress, injury, disease, and disruption to food supply; affecting community well-being through the damage to the economic and social fabric of communities) effects [13].

3.3. Intervening Conditions II: Biodiversity Loss

Wilson's biophilia hypothesis [57] states that human beings have the innate tendency to connect with nature. "Biophilia" means "love for life". Mental states of suffering—such as depression or anxiety—in many people, therefore, arise from a lack of spending time in natural surroundings. Biodiversity can be one element of these environments. Green urban spaces and other natural environments with a large number of different plants, for example, have a greater offer of sensory stimulations due to the many different colors, textures, and smells [58]. It has been demonstrated that contact with a high degree of biodiversity has a positive effect on mental health as well as on subjective well-being [59], and that the enormous loss of biodiversity that can be observed nowadays has a negative impact [60]. This is also the case in the built environment of Austrian cities.

3.4. Strategies: Sustainable City Development for a (Climate) Resilient Future of Work

In a review article by Engineer et al. [35], seven domains of integrative health (sleep, resilience, environment, movement, relationships, spirituality, and nutrition) are connected to possible interventions for the built environment that have the potential to enhance the health and well-being of residents. Themes of these interventions are related to light, views, biophilia, air quality, and spatial layout. Indoor environmental quality usually comprises thermal comfort, ventilation (indoor air quality), visual comfort, and acoustic comfort, and it influences human health and wellbeing as well as work performance [61]. Some of the different domains of possible strategies in the built environment (biophilia, air quality, light, and acoustics) will be discussed in the following subchapters in order to highlight strategies that interplay with mitigation and adaptation to climate change and urban strategies against biodiversity loss [44]. Work science-related strategies are important in this context and were therefore added to the domains.

3.4.1. Biophilia through Spatial Layout and Views

Many studies support nature recovery theories in different ways. Ulrich [62] examined records on recovery from surgery and found out that the assignment to a room with a window view of a natural setting has stronger restorative influences than a room with a window view of a brick building wall. Beukeboom et al. [63] showed that natural elements in hospital environments have the potential to reduce patients' feelings of stress and thereby to contribute to higher levels of well-being, but not only in hospital settings nature does play an important role.

Access to outdoor spaces and biophilic elements at home also contributes to better health and resilience [35,64,65]. Hartig et al. [66] found aspects relevant for work situations in offices: Walking in a natural environment could improve well-being and work performance at the same time. In her study about forests around the workplace, Shin [67] found a significant direct effect of forest views from windows on job satisfaction and stress. It is argued in this subchapter that biophilic elements at work—such as trees around the workplace or live plants in the office space—reduce stress and improve attention, productivity, and creativity [35,61]. This can be evaluated subjectively, but also measured objectively—for example, through the heart rate or the heart rate variability, which is an important stress indicator [68].

Scientists agree that there is an urgent need for action nowadays; the most effective strategy against the urban heat island effect is to enlarge urban green and water areas or to further expand already existing green and blue infrastructure in the private and the public sphere [36,69]. Green and blue infrastructure can support climate change adaptation and mitigation, biodiversity loss, and the promotion of health and well-being simultaneously. Air temperature can, for example, be reduced by up to 4 °C through evapotranspiration [70]. The binding capacity of rainwater can also be increased by up to 22% through the spread of green roofs [71].

Urban vegetation serves as a filter against air pollution as well, and thus promotes physical and mental health [72]. Maintaining and restoring tree cover provides not only a more promising view than a brick building wall, but also an ecosystem service of urban heat reduction [4], and it therefore contributes to an increase in thermal comfort [73].

3.4.2. Air Quality

Poor indoor air quality is the most important risk factor that is contributing to health problems, potentially causing drowsiness, sore throat, or acute respiratory problems [24,25]. The pollutants in the built environment that are harmful for occupant health and well-being can be classified in temperature-related (e.g., volatile organic compounds) and non-temperature-related (e.g., asbestos, polychlorinated biphenyls—PCB, polycyclic aromatic hydrocarbons—PAH). In indoor areas, relative humidity plays an important role in addition to room air temperature. If both factors are high, this usually also increases the release of chemical substances.

More important than the indoor temperature for the emissions-behavior of the building materials is the temperature of the building structure itself (e.g., for wooden buildings). With unchanged ventilation behavior of the users and denser construction methods without suitable indoor air technology, indoor pollutant concentrations will increase. The highest pollutant concentration is usually found in the so-called transition month of June. The risks are unequally distributed between different segments of the population, aggravating already existing health inequities. Carbon dioxide (CO_2), which is also an indicator of indoor air quality, is primarily caused by the occupants of a certain space. If more people work and live in a space for a longer period of time and with poor ventilation, levels of CO_2 increase subsequently [35]. This has a detrimental effect on cognitive performance, causing fatigue and poor judgement. Body posture, furniture placement, ventilation rates with, e.g., fresh air exchange, or operable windows and doors can positively impact the otherwise harmful accumulation of CO_2 [35].

Electronic devices in office environments have improved the efficiency of the work at the expense of indoor air quality [74]. Nevertheless, the increasingly widespread use of photocopiers and printers has been associated with the building sick syndrome [24,25]. Notably, older buildings are affected by climate change to an increased extent because, in the past, some substances such as asbestos, PCBs, and PAHs were not yet banned. In addition, without prior proper removal, the renovation work in existing buildings increases the mobilization of pollutants. There is also an increase in odors as the indoor temperature increases (environmental stressor: complaints and conflicts). This is especially a risk in the situation of the home office in or near the kitchens or smoking areas, and when less space is available than in an office environment. Indoor air quality can be improved through different measures: non-pharmaceutical measures or engineering controls such as air purifiers. Another way to ameliorate the situation is through the provision of a green environment by plantation. Outdoor air quality is an important factor for indoor air quality, as air is regularly transferred into the built environment, e.g., through mechanical ventilation, natural ventilation, and infiltration [25]. Therefore, it is important to consider the constant air exchange when striving to improve the outdoor air quality to the greatest extent possible.

3.4.3. Light

Artificial light, composed of visible light, as well as some ultraviolet and infrared radiation, not only has advantages for society. Too much of it can also disrupt the human biorhythm since the production of the sleep hormone melatonin is suppressed. This can lead to insomnia and other negative health effects such as neurodegeneration and different forms of cancer [75]. All photosensitive organisms are negatively affected by urban light pollution [76], which is an emerging environmental problem that comes along with urbanization and industrialization processes. Workplaces that do not have access to natural light can be equipped with tools for light therapy or with full spectrum light boxes that mimic circadian light. These can help to improve sleep and mood. In addition, the careful choice of furniture placement in relation to windows, optimal window sizes with daylight strategies such as shades, and intelligent design of other openings can be useful in this regard [77]. Initiatives to reduce urban light pollution should be included in urban planning in order to provide sustainable conditions for people and the environment. Energy consumption can be reduced in the context of climate change, but also the negative effects of light pollution for flora and fauna, e.g., due to disturbance of light-dependent nutrition and growth cycles, and can be addressed at the same time [76].

3.4.4. Acoustics

Not only thermal comfort, but also acoustic comfort—the perceived state of well-being and satisfaction with the acoustical conditions in an environment—plays an important role for the health, well-being, and work performance of city dwellers [78]. Noise pollution poses a potential health risk, especially for older people [79]. The human body switches to the alert mode when it is stressed by too loud or too many noises. It then releases stress hormones (adrenaline and cortisol), the heart starts to beat faster, blood pressure rises, and the respiratory rate increases. A large part of urban noise is caused by traffic. Traffic causes air pollution and vehicular emissions that are harmful for human health and that accelerate global climate change. Research also deals more and more with the impact of noise pollution on biodiversity. Anthropogenic urban noise (noise coming from cities and urbanization in general) and transportation noise (noise coming from all types of civil transportation activities), for example, pose a danger for many species [80].

3.4.5. Work Science

As outlined in the previous subchapters, biophilia, air quality, light, and acoustics are relevant issues for a more sustainable future of work. Yet, these aspects and their influence on occupational health are not adequately addressed in occupational safety and health, although significant synergies and co-benefits for mitigation and adaptation to climate change and for the preservation of flora and fauna exist. The STOP principle, a well-established hierarchy of strategies that comprises substitution (s), technical (t), organizational (o), and personal (p) measures, is regularly applied in occupational safety and health [81]. Often, several measures are combined to adequately reduce workloads, which leads to health promotion. Architectural accessibility or public, cool, and barrier-free spaces ("cool spots") in buildings are important aspects in this context [81]. Organizational issues and individual recommendations on equipment, health-promoting clothing, and behavior (e.g., work breaks or avoidance of midday heat) for the work at home under climate change and biodiversity loss are important in this context as well.

3.5. Consequences

The above-mentioned domains linked to the built environment offer potential to achieve some of the "Sustainable Development Goals" (SDGs) [82]. The environmental, economic, and social dimension of sustainable development could be addressed simultaneously. The following SDGs would be addressed through the implementation of adequate strategies in the named domains: Goal 4—Quality in Education: Ensure inclusive, equitable, and quality education and promote lifelong learning opportunities for all; Goal 8—Decent Work and Economic Growth: Promote sustained, inclusive, and sustainable economic growth, full and productive employment, and decent work for all; Goal 10—Reduce inequalities: reduce inequalities within and between countries; Goal 11—Sustainable Cities and Settlements: Make cities and settlements inclusive, safe, resilient, and sustainable. The aspects of education, work, reduction of inequalities, and sustainable urban development could be addressed simultaneously. By implementing more activities in the named domains, cities in Austria could come closer to reaching the Sustainable Development Goals 4, 8, 10, and 11. At the same time, goals that are related to biodiversity (e.g., Goal 3) and climate change (e.g., Goal 13) are being addressed through the proposed framework as well.

4. Discussion

One of the most important findings of the study was that, in future climate scenarios, overheating of the interior can no longer be prevented without active cooling measures and the integration of nature-based solutions in urban planning. Cooling systems with radiation surfaces by thermal activation of the room surfaces are a sufficiently effective and climate-neutral option in this regard [81]. The analysis of the dew point temperature concerning exceedance of 20 °C shows interesting results as well. In all three cities that were analyzed, such cases already occur, and the occurrence strongly increased during the last few decades. Future climate change will make such cases even more common and will substantially limit the cooling effect of passive cooling systems. It is worth mentioning that it is not the hottest cities, in terms of temperature maximum, that have the highest exceedance of the 20 °C dew point temperature.

Although individual comfort temperatures might be higher at home because employees can change them more freely than in offices, some values (e.g., TVOC and formaldehyde) are very high according to current research [83]. Recommendations on ergonomic equipment and behavior under climate change—ventilation techniques or active cooling measures, for example—are thus urgently needed for employees who are working from home in order to keep pollutants and sick building syndrome symptoms low [83,84].

The way we design and operate our built environment—for example, with regard to biophilic elements—influences the present conditions of human health, well-being, creativity, attention, and performance at work. Buildings play an important role for future living conditions as well, by being either a key driver for an increase in biodiversity, climate change mitigation, and adaptation, or by being an important obstacle in this regard [81].

Biophilia, outdoor and indoor air quality, light, and acoustics are important domains of strategies that can facilitate a more sustainable future of work. Yet, these aspects influencing occupational health are often not adequately addressed in work science, although significant synergies for mitigation and adaptation to climate change, and for the preservation of flora and fauna, might exist.

Although home offices have increased sharply since the beginning of the pandemic, there is still inconsistent empirical evidence on how this phenomenon influences different social and environmental aspects. Until now, mostly mental and physical changes—such as performance, health, and wellbeing—of people working from home have been studied, whereas the effects on the environment have been investigated only rarely [85].

With the adaptation of a framework that has been developed in a previous study [38], we present a holistic view by integrating the social dimension of sustainability with the economic and ecological dimensions, with climate change and biodiversity being important aspects. Barreto et al. [86] argue that the antagonism between sustainable development and corporate performance is questionable. Our framework on home offices supports this view. One of the challenges in this context is that, particularly, urban dwellers who are living and working in low-income neighborhoods may not have the necessary awareness or access to air conditioning or other cooling methods such as external sunshades. This issue needs to be addressed in order to prevent the exacerbation of already existing health risks and inequities. Work science related strategies are important but not sufficient to tackle the sustainability challenge that this topic poses.

Restorative environments, such as urban green space and forests, play a positive role in the effect on cognitive performance [68,73,87]. It is therefore important to provide access to restorative blue and green spaces for all inhabitants where they are able to disengage from work when it is needed. Such environments can be found through walks in nature, window views, office plants, nature break rooms, and nature related stimuli such as nature sounds, but also through companion animals such as cats or dogs [68,87]. Awareness on this topic and the related topic of biodiversity loss in cities needs to be raised, and adequate support needs to be provided to both employers and employees.

In order to ensure a high quality of life for the whole population in cities, planning for climate-resilient and sustainable urban development is essential, both in pandemic times and beyond [69]. A wide variety of strategies can be implemented for this purpose. They range from integrated and sustainable rainwater management, the broad implementation of various climate-effective nature-based solutions, and the implementation of high-quality urban green spaces to various specifications regarding open space design [36]. Above all—for the microclimatic optimization of the city—specifications regarding albedo, minimum structural thicknesses of substrates, and a minimum area that may not be sealed or built on are important [81]. Effective concepts—such as increased horizontal and vertical greening—already exist to counteract the negative and health-threatening consequences of the urban heat island effect and to promote thermal comfort. Such concepts need to be further implemented and evaluated, as grass and green roofs in urban areas might have a lower capability to reduce temperature and to improve thermal comfort than trees or whole forests [73].

Urban green spaces have positive effects on public (mental) health as well, by encouraging physical activity, reducing stress, and preventing non-communicable diseases that go hand in hand with a sedentary lifestyle [4,53]. They also have the potential to be part of a strategy for the inclusion of people with disabilities, but De Haas et al. [88] argue, in this regard, that a better cooperation between different public and private actors is urgently needed in order to make them more successful than is currently the case. Overall, the current study showed that, in addition to the SDG 8: Decent Work and Economic Growth, other SDGs should be envisaged in order to make our cities truly sustainable and to promote good health for all, now and in the future. The possible strategies—in the domains of biophilia, spatial layout, views, air quality, light, acoustics, and work science—are not mutually exclusive. The most effective solutions should involve a combination of them.

Limitations and Future Research

The most important disadvantage of the climate simulations was that, even in the high climate scenario, no new heat records occurred within the episodes. However, this is negligible when looking at two-year events, as performed in this study. Possible impacts related to new extreme temperatures with realistic magnitudes above 40 °C within the next decades are not considered. Although we did not calculate scenarios for old buildings in their unrenovated state (prior to 2050) in this study, it would be worthwhile to compare the outcomes of unrenovated buildings with those that have been renovated. This comparison could be explored in future studies.

Notably, the investigated Austrian locations belong, on a global view, to the same climate region that is representative of low elevation locations in Central Europe. According to the Köppen–Geiger classification, all belong to the class “Cfb” [89]. Thus, all findings discussed in this study are only valid for this warm temperate humid climate zone and cannot be transferred to other climate zones (e.g., tropical or subtropical).

We did not measure indoor and outdoor air quality in work environments (offices and home workplaces) in Austrian cities. The detailed study of the social dimension of the home office in Austria under climate change and biodiversity loss is beyond the scope of this study and should be examined in future studies to evaluate potential health risks, as well as environmental, social, economic, and health inequities, more rigorously.

There are only few high-quality papers underpinning the causal relationships of the holistic framework on the home office. Studies on the impact of green and blue infrastructure in the proximity of workplaces on work satisfaction, health, and well-being through indoor environmental quality is, for example, largely missing. Impacts of biodiversity (loss) on social sustainability need to be studied in different indoor and outdoor working environments, including in agricultural working spaces and practices. There is an increased need for research in modeling outdoor greening and quantifying its effectiveness on the indoor climate [81].

As not all aspects of indoor environmental quality could be addressed in this study, further studies should address aspects of cognitive function, creativity, work performance, and mental health at the workplace in the context of environmental quality and inequality. It would, furthermore, be interesting to study the social, economic and ecological effects of restorative environments on work- and study-related issues more profoundly. The rights of people with disabilities and children’s rights should, in any case, be considered in such studies [38].

5. Conclusions

This study highlighted several aspects that have a strong link to sustainability. For example, it was emphasized that the way we design and operate our built environment has a major impact on human health, well-being, creativity, and performance at work. It was also emphasized that buildings can be both an important driver for increasing biodiversity and adapting to climate change, as well as an important barrier in this regard. Another important aspect related to sustainability is the importance of nature-based solutions in urban planning to prevent indoor overheating. Here, the advantages of radiant surface cooling systems through thermal activation of indoor surfaces were particularly emphasized, as they represent a sufficiently effective and climate-neutral option.

Addressing the issue of indoor thermal comfort requires an inclusive, holistic, trans- and interdisciplinary approach that considers different dimensions of sustainability. It is important to focus on building design, energy-efficient technologies, and the use of sustainable materials in order to reduce energy consumption and reduce indoor temperatures. This approach will involve engineering solutions, design, and technology. At the same time social and behavioral aspects have to be addressed. Raising awareness about health risks related to climate change and biodiversity loss and providing guidelines and best practices for maintaining a comfortable indoor environment during (home) office work is important as well. Policies and educational programs are thus required for this aim.

In addition, the study identified various strategies related to biophilia, indoor and outdoor air quality, lighting, and acoustics as important domains that can facilitate a sustainable future of work. However, it was pointed out that these aspects that influence occupational health are often not adequately addressed in occupational science, even though significant synergies could exist for climate change mitigation and adaptation, as well as for flora and fauna conservation.

Overall, the study shows that, in addition to SDG 8: "Decent Work and Economic Growth", other SDGs should be considered to make our cities truly sustainable and promote good health for all, now and in the future. To achieve this, several strategies are needed, such as integrating nature-based solutions into urban planning, creating access to recreational green and blue spaces for all residents, and implementing concepts such as horizontal and vertical greening to promote well-being and health in urban environments.

On a global scale, climate change, as a common public perception, is affecting not just the growing number of people working from home in the post-COVID-19 generation, but everyone living on the planet. Policy recommendations to address global warming could be exemplarily based on implementing carbon pricing, investing in renewable energy, encouraging energy efficiency, implementing land-use policies, promoting public transportation, encouraging sustainable lifestyles, and supporting international cooperation. By implementing these measures, governments can reduce greenhouse gas emissions and take significant steps towards reducing the impact of global warming on the environment and people.

Author Contributions: Conceptualization, S.K.S., B.S., R.H., P.H., H.F. and D.H.; data curation, A.B., H.F., B.K. and D.H.; formal analysis, A.T., M.K., B.S., H.F. and B.K.; funding acquisition, L.C. and D.H.; investigation, A.T., M.K., A.B. and R.H.; methodology, S.K.S., A.T., B.S., L.C., R.H., P.H. and D.H.; project administration, L.C. and D.H.; resources, R.H., P.H., B.K. and D.H.; software, A.T. and A.B.; supervision, B.S., L.C., H.F. and D.H.; validation, B.S., P.H. and H.F.; writing—original draft, S.K.S., M.K., A.B., B.S., R.H., H.F. and D.H.; writing—review and editing, S.K.S., A.T., M.K., A.B., B.S., L.C., R.H., P.H., H.F., B.K. and D.H. All authors have read and agreed to the published version of the manuscript.

Funding: This research was supported by the Austrian Climate and Energy Fund (Klima- und Energiefonds), grant number KR19AC0K17544, and the FWF (Austrian Science Fund), grant number I4411, through the 2018–2019 BiodivERsA joint call for research proposals, under the BiodivERsA3 ERA-Net COFUND program.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Data used in this study are available from the corresponding author upon reasonable request.

Conflicts of Interest: The authors declare no conflict of interest.

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