Residential Buildings Committee (RBC) Residential Issue Brief:

Working from Home

The Issue

Overview:

The COVID-19 pandemic brought about a rapid and dramatic shift in the number of people working from home. This transition has had a significant societal impact and has raised numerous social challenges. For ASHRAE, the shift to more work from home has an impact on its mission, to serve humanity by advancing the arts and sciences of heating, ventilation, air conditioning, refrigeration, and their allied fields. Most notably key metrics for performance of the built environment, including occupant health, productivity, energy consumption, and carbon emissions could be impacted with a larger number of people working from home.

While some were working from home prior to the onset of the pandemic in early 2020, the desire to minimize face-to-face contact in an effort to reduce the transmission of the novel coronavirus increased that number dramatically. It is estimated that 5.7% of the American workforce (US Census Bureau 2021) and 5.4% of the workforce in the European Union was teleworking regularly in 2019 (Milasi et al. 2020). During the height of the pandemic, it was reported that 40% of Americans and members of the European Union were working from home (Barrero et al. 2021; Milasi et al. 2020). As the world has begun to cope with the impacts of the COVID-19 pandemic, some workers are beginning to return to offices and workplaces, but there is an acknowledgement that working-from-home is a phenomenon that is here to stay. Predictions on the number of workdays that will continue to be conducted from home vary greatly, however decreased commuting times and preferences to work from home will likely keep more people out of the office.

A survey taken in April 2021 estimated that 20% of workdays will be conducted from home after the pandemic (Barrero, Bloom, and Davis 2021). A survey in the United States carried out in March and April of 2022 indicated that those sentiments remained one year later, with 58% of respondents indicating that they had the opportunity to work from home at least one day per week and 35% indicating the option to work from home five days per week (McKinsey & Company 2022). Data from surveys taken since the start of the pandemic suggest a leveling off at an average of 30% of work hours from home (Maria, Bloom, and Davis 2022). Across the world, it is estimated that 1.5 days of work per week across the countries sampled were being done at home in mid-2021 and early 2022, ranging from 0.5 days in South Korea to 2.6 days in India (Aksoy et al. 2022). Data from the United States Bureau of Labor Statistics suggest that only approximately 7% of Americans worked from home directly because of the pandemic in August 2022 (Fitzpatrick 2022), suggesting that a large number of workers are choosing to work from home for other reasons such as convenience. While predictions are challenging, it is clear that the residential buildings sector is facing a change in the way that occupants will use their dwellings.

This transition to working from home will have an impact on the residential built environment. For ASHRAE, existing products may require amendment given this larger fraction of people working from

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home, and new activities may be warranted to address this transition. This Residential Issue Brief describes several key issues that may impact ASHRAE.

Changes in usage of residential spaces: expectations of comfort, health, productivity

Before the COVID-19 pandemic, many studies confirmed that working from home eliminates the inconveniences associated with commuting (time and stress) and generally provides a better work environment. The most substantial reported benefits covered were better concentration, less noise, fewer interruptions, more privacy, and better air quality, all of which contribute to workers' health and productivity (Tavares 2017; Montreuil and Lippel 2003). However, before COVID-19, telework was performed mainly by experienced white-collar professionals, while during the pandemic, forced telework was extended to staff with fewer at-home work accommodations and those across a broader income range (Cuerdo-Vilches et al. 2021). Often employees had to create improvised work setups in living rooms, kitchens, and bedrooms. A survey conducted in Spain (1800 respondents) showed that 42.2% of homes did not include any workspaces before the lockdown (Cuerdo-Vilches, Navas-Martín, and Oteiza 2021). Moreover, because of the closure of schools, many parents were forced to work while concurrently supervising their children and their at-home schooling. As a result of these changes, numerous employees have experienced lower work productivity, lower motivation, increased stress, and poorer mental health (Buomprisco et al. 2021; Toniolo-Barrios and Pitt 2021).

The state of the working environment differs strongly between homes. A survey performed between April and June 2020 (Xiao et al. 2021) documented some of these findings, with 988 completed questionnaires filled out by individuals working in California (47.3%), 39 other states in the U.S. (35.8%), countries outside of the U.S. (6.4%), and unidentified areas (10.5%). Thirty-three percent of respondents declared that they had a dedicated room for work activities, 50.3% that they had a dedicated space in a room with other uses, and 16.7% stated that they work in various places, rooms, or locations around their homes. Satisfaction with indoor environmental quality (IEQ) factors related to the home workspace was rated on a 5-point Likert-type scale from 1 (extremely dissatisfied) to 5 (extremely satisfied). The satisfaction with indoor air quality was 4.14 (0.84) [mean (standard deviation)]. Other components of IEQ were scored slightly lower: thermal environment 4.00 (1.07), visual environment 3.93 (0.83), and noise 3.48 (1.22). Working in a dedicated room and satisfaction with indoor environmental parameters were related to a lower number of reported physical and mental health problems. A pilot study conducted in McAllen, Texas (Roh et al. 2021) also indicated that sick building syndrome symptoms were more frequent during work from home than during work in an office.

An important result from this literature review was that only 11.4% of participants in a U.S. survey on the impacts of working from home during the COVID-19 pandemic on well-being (Xiao et al. 2021) declared that they knew if and how their workstation, including its indoor environmental quality, was affecting their health, well-being, or productivity. Additionally, only a small group of respondents (2.4%) reported that they consulted a professional to adjust their workstations, be it related to ergonomics or IEQ. This lack of knowledge of the workspace in homes could motivate the expanded use of simple indoor environmental quality sensors that constantly monitor, e.g., air temperature, humidity, CO_2, TVOC, $PM_{2.5}$ along with the guidance and tools to interpret data collected from these sensors. While expectations of comfort may differ between offices and homes, there should still be the same expectation that both spaces provide an environment conducive to health and productivity.

Changes in contaminants within homes

With adults working from home and children studying at home, there are several factors related to indoor air quality that are expected to change. First there is the increase in emissions from human metabolic processes: CO_2, water vapor and general bioeffluents (including odors). It is likely that more cooking is done at home and more cooking related contaminants are released into the home, primarily particles, water vapor and odors (Sun and Wallace 2021). If cooking with gas, this results in increases in products of combustion, including CO_2 and, more importantly, NO_2 and particles that regularly exceed health-based guidelines in homes (H. Zhao et al. 2021; Y. Zhao and Zhao 2018; Singer et al. 2017). Other potential issues could include certain individual/social/cultural habits, such as the burning of incense sticks, the use of aroma diffusers, or smoking.

There may also be other, less obvious effects. For example, formaldehyde emissions can vary substantially and are strongly dependent on temperature and humidity. If a home is heated during the day when it was not previously, then one would expect higher emission rates for formaldehyde with an increase in concentration (emission rates increase about 10% for every degree C temperature increase (H. Zhao et al. 2022), though there is great variation in that rate (Andersen et al. 1975; Salthammer et al. 1995; Poppendieck et al. 2015)). For air-conditioned homes the effect is reversed with lower formaldehyde emission rates compared to the previously uncooled home. Similarly, there are impacts of humidity where higher emission rates are expected because the emission rate increases with relative humidity (RH), and RH is likely to increase in a home that is more heavily occupied (although this may be offset by more dehumidification due to air conditioner operation in warmer climates).

Overall, an increase in indoor contaminants, moisture, and odor are expected when homes are also used as offices and alternatives to schools and daycare for children. This impact, however, is likely to vary widely. Data are lacking on how much more cooking has been done in homes as a result of the pandemic, so making conclusions on the impact of cooking is difficult, although one study using American Time Use Survey (ATUS) data suggests that the amount of time people spend in the kitchen and dining areas, including cooking activities, has increased (Mitra et al. 2022). The effects of increased occupancy depend significantly on the size of the home. While studies suggest that the amount of time that people are spending at home has increased as a result of the pandemic (Moreland et al 2020; Mitra et al 2022), adding one more day-time occupant to a large home may result in very small changes in indoor conditions, whereas adding four day-time occupants to a small apartment will likely result in substantial changes.

Another question where data are lacking is how people may have changed ventilation practices in their homes when working from home. It is possible that they opened windows more often or used passive (e.g., trickle vents) or mechanical ventilation systems more often. One study of six homes in Spain indicated that people became more aware of indoor air quality issues during lockdown events when forced to work/stay at home and ventilated their homes more frequently (Fernández-Agüera et al. 2022). In this study, prior to lockdown, occupants were unaware of or paid little heed to changes in indoor air quality, failed to perceive stuffiness, and, as a rule, reported symptoms of discomfort only at night during the summer months. During lockdown, however, users came to attach greater importance to air quality, and a greater sensitivity to odors and a heightened awareness of CO_2 concentration prompted them to ventilate their homes more frequently. In the spring of 2020, occupants also indicated a wider spectrum of indisposition, in particular in connection with sleep patterns.

In addition to changes in indoor conditions in homes, it is useful to examine how exposures change for individuals - primarily swapping eight hours in an office environment for a home environment and removing exposures during commuting. Many studies have examined exposure to contaminants of concern during commuting. These studies have shown that time spent commuting correlates with increased particulate matter (PM) and volatile organic compound (VOC) exposures (such as benzene) (Cattaneo et al. 2021), represents a substantial (10% to 20%) fraction of total VOC exposure (Chan et al. 1991), and exposes individuals to levels of contaminants that are substantially higher than in homes (e.g., 22 μg/m^3 to 85 μg/m^3 for $PM_{2.5}$ (Karanasiou et al. 2014)). It is reasonable to say that not commuting reduces an individual's exposure to some contaminants of concern.

Several studies quantitatively compared contaminant conditions during work from home and corresponding office buildings. Although samples were somewhat limited, results obtained in the U.S. (Roh et al. 2021; Sarnosky et al. 2021), Italy (Pietrogrande et al. 2021), and Norway (Justo Alonso et al. 2022) were very similar. Usually, the concentrations of $PM_{2.5}$, PM_{10}, Total Volatile Organic Compounds (TVOC), and/or CO_2 in homes were higher than in office buildings. These differences typically result from the basic (or non-existent) ventilation systems in homes.

When comparing home and office environments, the best approach is to compare the offices and homes of the same workers. A study specifically focused on pandemic-related changes (Roh et al. 2021) showed $PM_{2.5}$ levels in households while working from home were significantly higher than in offices for all participants. The $PM_{2.5}$ levels in all households exceeded the health-based annual mean standard (12 μg/m^3), whereas 90% of offices were in compliance. This study suggested that working from home might have a detrimental health impact due to poor IAQ and providing interventions to remote employees should be considered. Another direct comparison between homes and office environments for formaldehyde showed little difference between homes (8.4 μg/m^3 to 20 μg/m^3) and offices (4.6 μg/m^3 to 17 μg/m^3) (Abelmann et al. 2020). More general comparisons between home and work environments are hampered by most studies being individual case studies for either homes or offices in different places and involving different occupants, making them difficult to compare.

In summary, it is likely that working from home will lead to an increase in occupancy-related contaminants in homes and that these home exposures are higher than in offices, although there is substantial variation depending on home occupancy, occupant activities, quality of ventilation provided at home or office, etc. Offsetting factors are reduced exposure to elevated contaminant levels while commuting and a possible increase in people's awareness of IAQ in their homes.

Changes in ventilation

Office activities typically involve reading, writing, typing, filing, etc., while sleeping, leisure, house cleaning, cooking, etc. are usually associated with homes. Although temperature requirements are similar for both the workplace and the home, both ranging from 19 °C to 28 °C (67°F to 82°F), people typically prefer a slightly higher temperature at home both in the cooling and heating seasons with less need for tight humidity control (ASHRAE 2021). Minimum ventilation rates as specified by standards such as ASHRAE 62.1, 62.2, and EN 16798-1 are slightly different as well. In the ASHRAE 62.1 standard, the minimum air flow rate is 2.8 L/s/person [6 cubic feet per minute (cfm)/person] for offices (ASHRAE 2022a), and in ASHRAE 62.2 standard it is 1.5 L/s/(100 m^2) [3 cfm/(1000 ft^2)] plus 3.5 L/s/person (7.5 cfm/person) for homes (ASHRAE 2022b). Similar differences occur in EN 16798-1, where minimum ventilation rates in residential and non-residential buildings can be based on different rules that do not perfectly match for the two types of buildings. Ventilation in non-residential buildings can be based on floor area, number of people, a combination of people and building components, or CO_2 levels. Ventilation in residential buildings is based on air changes per hour for each room, outside air supply or exhaust rates for rooms, or as an overall required air-change rate (The European Committee for Standardization 2019). The different ventilation rates in these standards raise a question on whether residential ventilation requirements lead to a suitable environment for effective work efficiency when working from home. A key difference between many work locations and homes is that the vast majority of homes are not provided with any mechanical ventilation and rely on natural infiltration from building envelope leaks or from open windows. It is also to be noted that some of the prevailing residential air-conditioning systems do not provide outdoor air for ventilation and just recirculate room air for cooling and thermal comfort. This leads to great variability and uncertainty in home ventilation. Furthermore, without a mechanical system, air entering homes is not treated thermally and may result in poor IEQ due to discomfort, such as drafts. The lack of a mechanical ventilation system also limits the ability to treat air for contaminants, e.g., office ventilation systems can include filtration to remove particles.

As discussed earlier, working from home could bring about changes in contaminant profiles in homes and will pose significant IAQ demands on residential buildings that may not be equipped with the capabilities to provide them. In assessing how to properly consider ventilation and IEQ as the home is turned into a workplace, a recently published ASHRAE Residential Issue Brief titled "Ventilation, IEQ and Sleep Quality in Bedrooms" (ASHRAE 2022c) provides some corollaries and lists design features and operating targets that should be considered to ensure that a home's multiple uses, e.g., as a workplace and a place of sleep, do not conflict with each other. It identifies the importance of a holistic approach to IEQ (thermal, IAQ, light, noise), sleep quality and energy in different types of residential buildings across different climates and socioeconomic realms.

Changes in Equipment

The increase in working from home may lead to changes in the equipment used in homes. Little documented data have been presented on the impact of the pandemic on purchases of heating and cooling equipment, water heaters, or other appliances. However, some anecdotal reports suggest that homeowners have upgraded home appliances with greater frequency given their increased presence at home and may put a greater premium on high-performing and energy-efficient heating and cooling systems given their greater use. For HVAC systems, a greater appreciation of the value of ventilation may increase the incorporation of mechanical ventilation into systems, and that trend may change the sensible heat ratios that heat pumps and air conditioners must handle. Additionally, filters with higher efficacy may be incorporated into central systems, and the use of in-room air cleaners including homemade systems (e.g., a MERV 13 filter taped onto a room fan) may increase. Greater time spent at home may also make occupants more aware of the functioning of their systems, and some have suggested that remote diagnostics may become more popular to diagnose and fix problems in a more rapid manner. The controls of systems may be affected by a greater fraction of work from home. Conventional setback controls may be used less given greater residential occupancy, but zoning within residential may become more cost-effective if small portions of homes are used for large parts of the day. Finally, acoustic considerations of HVAC systems may become more pronounced with the need for concentration and video meetings (Torresin et al. 2021).

Changes in resultant electric load profiles and interactions with grid

The COVID-19 pandemic has also had a notable impact on residential building's energy use patterns as a result of changes in people's use of buildings, including spending less time in the office, at school, in restaurants, and traveling, and more time at home. Recent research has focused on analysis of both building and electric grid impacts. At the building level, research efforts suggest that overall, the energy use patterns of residential buildings have changed, as have residential occupancy profiles, as a result of the pandemic. This has been found to be particularly different during the typical workday hours (Kawka and Cetin 2021; Li et al. 2021), when pre-pandemic few people worked from home or attended school remotely, as compared to during the pandemic. Overall residential energy use has increased up to 32%, whereas peak demands have been found to be up to 53% higher (Burleyson et al. 2021; Deiss et al. 2021; Krarti and Aldubyan 2021). For specific types of energy use, both weather-normalized heating, ventilation and air conditioning (HVAC) and non-HVAC energy use have increased (Kawka and Cetin 2021). Weekend energy use patterns have been closer to pre-pandemic as compared to weekdays.

Considering the impacts on the electric grid, the early stages of the pandemic resulted in lower overall grid electricity demand, but an increasing percentage from residential buildings and decreased percent from commercial buildings. Given the load shapes of residential and commercial buildings are different, this also impacts the load shape of the grid. While less studied, more people working and staying at home impacts the demand reduction potential of residential buildings' systems. While the peak demand, and thus potential to reduce demand, may be higher in residential buildings as a result of the pandemic, with more people at home, it is also more likely that changes in use of various energy consuming systems may impact occupants' comfort and/or daily activities.

What does this mean for ASHRAE?

For ASHRAE and its members, one key impact of greater instances of working from home is a blurring of the lines between typical residential and commercial uses of buildings. Moving work to a home may bring occupational requirements into a home, thereby forcing homes to meet multiple requirements. This change may impact some of ASHRAE's key products. For example, a number of ASHRAE standards such as the 62 series for Ventilation and Acceptable Indoor Air Quality are differentiated by building type. ASHRAE will need to consider the appropriateness of standards that have historically been classified as residential standards when homes are used more frequently for office work.

A related societal issue that may impact ASHRAE is the responsibility of employers to ensure adequate workspaces for employees. Many telework agreements and training resources stress the need for employees to create ergonomic workspaces. Since research suggests a correlation between the environment and productivity, guidance from employers may also need to stress the importance of the indoor environment. Given that regulations are different in homes compared to office environments, sorting out the responsibilities will be important. Conceivably, regulations could require employers to improve the environmental conditions under which employees work. In that case, alternative HVAC solutions may be required, including standards, guidance documents, and equipment.

The altered usage of homes will also impact some of ASHRAE's efforts. Previous assumptions on occupancy that are presented in Handbooks, used in ASHRAE research to evaluate technologies, and considered in standards for assessment of building and equipment performance may need to be reconsidered. Different demands on residential buildings and the equipment that conditions them may necessitate new guidance from ASHRAE for residential building professionals and the public at-large.

With ASHRAE striving to enable the decarbonization of the building stock, different usage of residential buildings will affect control approaches to align energy usage in homes with times when the grid is at its lowest carbon intensity.

The Role of ASHRAE

ASHRAE has the technical knowledge to provide guidance to engineers, architects, building owners, and occupants to create working environments in the home that maximize productivity and comfort while reducing energy costs and environmental impacts. To assist society in creating healthy and productive indoor environments as more workers embrace working from home, ASHRAE should consider pursuing the following activities:

1) Develop guidance documents on creating an appropriate indoor environment for the home office. This guidance could include sensing to assess the indoor environment, retrofitting homes given that they may not have mechanical ventilation or filtration, maintenance of systems, and the use of personal comfort stations. The guidance should also address situations

when a home may not have a dedicated office space. Documents would be intended for both ASHRAE members and the general public.

2) Assess the boundaries between standards that are currently differentiated by residential and commercial uses (e.g., Standards 62.1 and 62.2) to accommodate working from home. As an example, options could include additions to either Standard 62.1 or 62.2 to address this new type of use or a new standard to bridge the gap between the two.

3) Conduct research to create representative occupancy, thermal (sensible and latent) demand, and electric and fuel load profiles in residential buildings used as home offices. This effort is needed for building energy modelling purposes as well as for predictions of the impact of the residential sector on the grid.

4) Promote research to assess exposures to contaminants during greater instances of working from home relative to those to which people would normally be exposed in homes and workplaces.

5) Provide presentations (e.g., Distinguished Lectures, Conferences, ASHRAE Learning Institute activities) to share best practices for creating home offices.

6) Foster outreach efforts to raise IEQ awareness in the society at large (focussing on general public who would not have domain knowledge but are users of residential environments), which would involve demystifying the subject and presenting the issues and practical solutions through infographics or with other easy-to-understand methods via the ASHRAE website and publications.

References

Abelmann, Anders, Abigail R. McEwen, Jason T. Lotter, and Joshua R. Maskrey. 2020. "Survey of 24-h Personal Formaldehyde Exposures in Geographically Distributed Urban Office Workers in the USA." *Environmental Science and Pollution Research* 27 (14): 17250–57. https://doi.org/10.1007/s11356-020-08218-0.

Aksoy, Cevat Giray, Jose Maria Barrero, Nicholas Bloom, Steven J. Davis, Mathias Dolls, and Pablo Zarate. 2022. "Working from Home Around the World." Working Paper. Working Paper Series. National Bureau of Economic Research. https://doi.org/10.3386/w30446.

Andersen, Ib, G. R. Lundqvist, and L. Mølhave. 1975. "Indoor Air Pollution Due to Chipboard Used as a Construction Material." *Atmospheric Environment (1967)* 9 (12): 1121–27. https://doi.org/10.1016/0004-6981(75)90188-2.

ASHRAE. 2021. "ANSI/ASHRAE Standard 55 – Thermal Environmental Conditions for Human Occupancy." ASHRAE. https://www.ashrae.org/technical-resources/bookstore/standard-55-thermal-environmental-conditions-for-human-occupancy.

———. 2022a. "ANSI/ASHRAE Standard 62.1: Ventilation and Acceptable Indoor Air Quality." ASHRAE. https://www.ashrae.org/technical-resources/bookstore/standards-62-1-62-2.

———. 2022b. "ANSI/ASHRAE Standard 62.2: Ventilation and Acceptable Indoor Air Quality in Residential Buildings." ASHRAE. https://www.ashrae.org/technical-resources/bookstore/standards-62-1-62-2.

———. 2022c. "Residential Issue Brief: Ventilation, IEQ, and Sleep Quality in Bedrooms." https://www.ashrae.org/file%20library/communities/committees/standing%20committees/residential%20building%20committee%20(rbc)/issue-brief---ventilation-ieq-and-sleep-quality-in-bedrooms-final-4.pdf.

Barrero, Jose Maria, Nicholas Bloom, and Steven J. Davis. 2021. "Why Working from Home Will Stick." Working Paper. Working Paper Series. National Bureau of Economic Research. https://doi.org/10.3386/w28731.

Buomprisco, Giuseppe, Serafino Ricci, Roberto Perri, and Simone De Sio. 2021. "Health and Telework: New Challenges after COVID-19 Pandemic." *European Journal of Environment and Public Health* 5 (2): em0073. https://doi.org/10.21601/ejeph/9705.

Burleyson, Casey D., Aowabin Rahman, Jennie S. Rice, Amanda D. Smith, and Nathalie Voisin. 2021. "Multiscale Effects Masked the Impact of the COVID-19 Pandemic on Electricity Demand in the United States." *Applied Energy* 304 (December): 117711. https://doi.org/10.1016/j.apenergy.2021.117711.

Cattaneo, Andrea, Laura Campo, Simona Iodice, Andrea Spinazzè, Luca Olgiati, Francesca Borghi, Elisa Polledri, et al. 2021. "Environmental and Biological Monitoring of Personal Exposure to Air Pollutants of Adult People Living in a Metropolitan Area." *Science of The Total Environment* 767 (May): 144916. https://doi.org/10.1016/j.scitotenv.2020.144916.

Chan, Chang-Chuan, John D. Spengler, Halûk Özkaynak, and Myrto Lefkopoulou. 1991. "Commuter Exposures to VOCs in Boston, Massachusetts." *Journal of the Air & Waste Management Association* 41 (12): 1594–1600. https://doi.org/10.1080/10473289.1991.10466955.

Cuerdo-Vilches, Teresa, Miguel Ángel Navas-Martín, Sebastià March, and Ignacio Oteiza. 2021. "Adequacy of Telework Spaces in Homes during the Lockdown in Madrid, According to Socioeconomic Factors and Home Features." *Sustainable Cities and Society* 75 (December): 103262. https://doi.org/10.1016/j.scs.2021.103262.

Cuerdo-Vilches, Teresa, Miguel Ángel Navas-Martín, and Ignacio Oteiza. 2021. "Working from Home: Is Our Housing Ready?" *International Journal of Environmental Research and Public Health* 18 (14): 7329. https://doi.org/10.3390/ijerph18147329.

Deiss, Branden M., Mallori Herishko, Lauren Wright, Michelle Maliborska, and J. Patrick Abulencia. 2021. "Analysis of Energy Consumption in Commercial and Residential Buildings in New York City before and during the COVID-19 Pandemic." *Sustainability* 13 (21): 11586. https://doi.org/10.3390/su132111586.

Fernández-Agüera, Jesica, Samuel Domínguez-Amarillo, Miguel Ángel Campano, and Hanan Al-Khatri. 2022. "Effects of Covid-Induced Lockdown on Inhabitants' Perception of Indoor Air Quality in Naturally Ventilated Homes." *Air Quality, Atmosphere & Health*, October. https://doi.org/10.1007/s11869-022-01239-3.

Fitzpatrick, Alex. 2022. "Welcome to Remote Work's Equilibrium Point." Axios. July 12, 2022. https://www.axios.com/2022/07/12/remote-work-equilibrium-point.

Justo Alonso, M., T. N. Moazami, P. Liu, R. B. Jørgensen, and H. M. Mathisen. 2022. "Assessing the Indoor Air Quality and Their Predictor Variable in 21 Home Offices during the Covid-19 Pandemic in Norway." *Building and Environment* 225 (November): 109580. https://doi.org/10.1016/j.buildenv.2022.109580.

Karanasiou, Angeliki, Mar Viana, Xavier Querol, Teresa Moreno, and Frank de Leeuw. 2014. "Assessment of Personal Exposure to Particulate Air Pollution during Commuting in European Cities—Recommendations and Policy Implications." *Science of The Total Environment* 490 (August): 785–97. https://doi.org/10.1016/j.scitotenv.2014.05.036.

Kawka, Emily, and Kristen Cetin. 2021. "Impacts of COVID-19 on Residential Building Energy Use and Performance." *Building and Environment* 205 (November): 108200. https://doi.org/10.1016/j.buildenv.2021.108200.

Krarti, Moncef, and Mohammad Aldubyan. 2021. "Review Analysis of COVID-19 Impact on Electricity Demand for Residential Buildings." *Renewable and Sustainable Energy Reviews* 143 (June): 110888. https://doi.org/10.1016/j.rser.2021.110888.

Li, Lechen, Christoph J. Meinrenken, Vijay Modi, and Patricia J. Culligan. 2021. "Impacts of COVID-19 Related Stay-at-Home Restrictions on Residential Electricity Use and Implications for Future Grid Stability." *Energy and Buildings* 251 (November): 111330. https://doi.org/10.1016/j.enbuild.2021.111330.

Maria, Jose, Nicholas Bloom, and Steven J Davis. 2022. "Survey of Working Arrangements and Attitudes (SWAA)." 2022. https://wfhresearch.com/.

McKinsey & Company. 2022. "Is Remote Work Effective: We Finally Have the Data." 2022. https://www.mckinsey.com/industries/real-estate/our-insights/americans-are-embracing-flexible-work-and-they-want-more-of-it.

Milasi, Santo, Ignacio Gonzalez-Vazquez, and Enrique Fernandez-Macias. 2020. "Telework in the EU before and after the COVID-19: Where We Were, Where We Head To." JRC 120945. Science for Policy Briefs. Joint Research Centre - European Commission. https://joint-research-centre.ec.europa.eu/system/files/2021-06/jrc120945_policy_brief_-_covid_and_telework_final.pdf.

Montreuil, Sylvie, and Katherine Lippel. 2003. "Telework and Occupational Health: A Quebec Empirical Study and Regulatory Implications." *Safety Science* 41 (4): 339–58. https://doi.org/10.1016/S0925-7535(02)00042-5.

Pietrogrande, Maria Chiara, Lucia Casari, Giorgia Demaria, and Mara Russo. 2021. "Indoor Air Quality in Domestic Environments during Periods Close to Italian COVID-19 Lockdown." *International Journal of Environmental Research and Public Health* 18 (8): 4060. https://doi.org/10.3390/ijerph18084060.

Poppendieck, Dustin G., Lisa C. Ng, Andrew K. Persily, and Alfred T. Hodgson. 2015. "Long Term Air Quality Monitoring in a Net-Zero Energy Residence Designed with Low Emitting Interior Products." *Building and Environment* 94, Part 1 (December): 33–42. https://doi.org/10.1016/j.buildenv.2015.07.001.

Roh, Taehyun, Alejandro Moreno-Rangel, Juha Baek, Alexander Obeng, Nishat Tasnim Hasan, and Genny Carrillo. 2021. "Indoor Air Quality and Health Outcomes in Employees Working from Home during the COVID-19 Pandemic: A Pilot Study." *Atmosphere* 12 (12): 1665. https://doi.org/10.3390/atmos12121665.

Salthammer, T., F. Fuhrmann, S. Kaufhold, B. Meyer, and A. Schwarz. 1995. "Effects of Climatic Parameters on Formaldehyde Concentrations in Indoor Air." *Indoor Air* 5 (2): 120–28. https://doi.org/10.1111/j.1600-0668.1995.t01-2-00003.x.

Sarnosky, Kamrie, Mark Benden, Leslie Cizmas, Annette Regan, and Garett Sansom. 2021. "Remote Work and the Environment: Exploratory Analysis of Indoor Air Quality of Commercial Offices and the Home Office," February. https://doi.org/10.21203/rs.3.rs-146008/v1.

Singer, Brett C., Rebecca Zarin Pass, William W. Delp, David M. Lorenzetti, and Randy L. Maddalena. 2017. "Pollutant Concentrations and Emission Rates from Natural Gas Cooking Burners without and with Range Hood Exhaust in Nine California Homes." *Building and Environment* 122 (September): 215–29. https://doi.org/10.1016/j.buildenv.2017.06.021.

Sun, Liu, and Lance A. Wallace. 2021. "Residential Cooking and Use of Kitchen Ventilation: The Impact on Exposure." *Journal of the Air & Waste Management Association* 71 (7): 830–43. https://doi.org/10.1080/10962247.2020.1823525.

Tavares, Aida Isabel. 2017. "Telework and Health Effects Review." *International Journal of Healthcare* 3 (2): 30. https://doi.org/10.5430/ijh.v3n2p30.

The European Committee for Standardization. 2019. "BS EN 16798-1: Energy Performance of Buildings. Ventilation for Buildings - Indoor Environmental Input Parameters for Design and Assessment of Energy Performance of Buildings Addressing Indoor Air Quality, Thermal Environment, Lighting and Acoustics." https://knowledge.bsigroup.com/products/energy-performance-of-buildings-

ventilation-for-buildings-indoor-environmental-input-parameters-for-design-and-assessment-of-energy-performance-of-buildings-addressing-indoor-air-quality-thermal-environment-lighting-and-acoustics-module/tracked-changes.
Toniolo-Barrios, Mariana, and Leyland Pitt. 2021. "Mindfulness and the Challenges of Working from Home in Times of Crisis." *Business Horizons* 64 (2): 189–97. https://doi.org/10.1016/j.bushor.2020.09.004.
Torresin, Simone, Rossano Albatici, Francesco Aletta, Francesco Babich, Tin Oberman, Agnieszka Elzbieta Stawinoga, and Jian Kang. 2021. "Relaxing and Working from Home: Associations between Heating, Ventilation and Cooling System Typologies and Indoor Soundscape Evaluation." In *8th International Building Physics Conference, IBPC 2021, August 25, 2021 - August 27, 2021*. Vol. 2069. Journal of Physics: Conference Series. Copenhagen, Virtual, Denmark: IOP Publishing Ltd. https://doi.org/10.1088/1742-6596/2069/1/012174.
US Census Bureau. 2021. "The Number of People Primarily Working From Home Tripled Between 2019 and 2021." Census.Gov. 2021. https://www.census.gov/newsroom/press-releases/2022/people-working-from-home.html.
Xiao, Yijing, Burcin Becerik-Gerber, Gale Lucas, and Shawn C. Roll. 2021. "Impacts of Working From Home During COVID-19 Pandemic on Physical and Mental Well-Being of Office Workstation Users." *Journal of Occupational and Environmental Medicine* 63 (3): 181–90. https://doi.org/10.1097/JOM.0000000000002097.
Zhao, Haoran, Wanyu R. Chan, Sebastian Cohn, William W. Delp, Iain S. Walker, and Brett C. Singer. 2021. "Indoor Air Quality in New and Renovated Low-Income Apartments with Mechanical Ventilation and Natural Gas Cooking in California." *Indoor Air* 31 (3): 717–29. https://doi.org/10.1111/ina.12764.
Zhao, Haoran, Iain S. Walker, Michael D. Sohn, and Brennan Less. 2022. "A Time-Varying Model for Predicting Formaldehyde Emission Rates in Homes." *International Journal of Environmental Research and Public Health* 19 (11): 6603. https://doi.org/10.3390/ijerph19116603.
Zhao, Yuejing, and Bin Zhao. 2018. "Emissions of Air Pollutants from Chinese Cooking: A Literature Review." *Building Simulation* 11 (5): 977–95. https://doi.org/10.1007/s12273-018-0456-6.

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