Working from Home And the Impacts on Residential Buildings

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The COVID-19 pandemic brought about a rapid and dramatic shift in the number of people working from home. For ASHRAE, the shift to more work from home has an impact directly on its members who work from home and indirectly on those ASHRAE members serve. 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 their residences.

While some were working from home prior to the pandemic's onset in early 2020, precautions to reduce the transmission of the novel coronavirus increased this number dramatically. It is estimated that 5.7% of the American workforce[1] and 5.4% of the European Union's was working from home regularly in 2019.[2] During the pandemic's height in 2020, it was reported that 40% of Americans and members of the European Union were working from home.[2,3] Even as many employees have now returned to offices, there is an acknowledgement that working from home is here to stay.

Predictions vary greatly on the number of workdays that will continue to be conducted from home. A survey in the U.S. carried out in March and April of 2022 showed 58% of respondents indicating 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.[4] Data from surveys taken since the start of the pandemic suggest an average of 30% of work hours being conducted from home going forward.[5] While predictions are challenging, it is clear that the residential buildings sector is facing a change in the way working adults use their dwellings.

Changes in Use of Residential Spaces: Expectations of Comfort, Health, Productivity

One change has been the typical use of residential building spaces and the accompanying expectations of the indoor environment for work. Before the COVID-19 pandemic, many studies concluded that working from home generally provides a better work environment.

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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.[6,7] However, this work from home was performed mainly by experienced white-collar professionals, while during the pandemic, forced work from home was extended to staff with lesser accommodations for at-home work and those across a broader income range.[8]

The greater incidence of working from home provides insight on the impact of the indoor environment on worker productivity, health and comfort, but it also brings to light that many are not aware of indoor environmental quality (IEQ). A survey performed between April and June 2020[9] found that 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,[10] also indicated that sick building syndrome (SBS) symptoms were more frequent during work from home than during work in an office.

Another important observation is that only 11.4% of participants in the survey by Xiao, et al.,[9] declared that they knew if and how their workstation, including its IEQ, was affecting their health, well-being or productivity. This lack of knowledge of the workspace in homes and incidence of SBS could motivate the expanded use of simple IEQ sensors that constantly monitor key parameters along with 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 expectation that both provide an environment conducive to health and productivity. Improvements to residential IEQ will have a positive impact on parts of the population such as the elderly that have traditionally spent more time in their homes even prior to the pandemic.

Changes in Contaminants Within Homes

With people working from home, several factors related to indoor air quality (IAQ) are expected to change. First 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.[11,12]

Other, less obvious effects may exist. 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, one would expect higher emission rates for formaldehyde with an increase in concentration. For air-conditioned homes the effect is reversed—lower formaldehyde emission rates compared to the previously uncooled home.

The impact of working from home on contaminant levels 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 data suggests the amount of time people spend in the kitchen and dining areas, including cooking activities, has increased.[13]

Several studies quantitatively compared contaminant conditions during work from home to those of office buildings.[10,14–16] The concentrations of $PM_{2.5}$, PM_{10}, total volatile organic compounds, and CO_2 in homes were usually higher than in office buildings. These differences typically result from the basic (or often nonexistent) 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[10] 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 $\mu g/m^3$), whereas 90% of offices were in compliance.

Another direct comparison between homes and office environments for formaldehyde showed little difference between homes (8.4 $\mu g/m^3$ to 20 $\mu g/m^3$) and offices (4.6 $\mu g/m^3$ to 17 $\mu g/m^3$).[17] 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.

Changes in Ventilation

Ventilation in nonresidential 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 can be based on floor area, number of occupants per dwelling, air changes per hour for each room, outdoor air supply or exhaust rates for rooms and/or as an overall required air-change rate.[18,19] The different ventilation rates in these standards raise a question of whether residential ventilation requirements lead to a suitable environment for effective work efficiency when working from home.

A key difference between many office work locations and homes is the vast majority of homes are not provided with any mechanical ventilation and rely on natural infiltration from building envelope leaks or open windows. 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 discomfort. The lack of mechanical ventilation also limits the ability to treat air for contaminants such as filtration for $PM_{2.5}$ removal.

Changes in Resultant Electric Load Profiles And Grid Interactions

The COVID-19 pandemic also had a notable impact on residential building energy use patterns as a result of changes in people's use of buildings. At the building level, research efforts suggest that the pandemic changed the energy use patterns and occupancy profiles of residential buildings. This change has been found to be particularly significant during the typical workday hours,[20,21] when, pre-pandemic, few people worked from home or attended school remotely. Overall residential energy use increased up to 32%, whereas peak demands were found to be up to 53% higher.[22–24] For specific types of energy use, both weather-normalized HVAC and non-HVAC energy use increased.[20] Weekend energy use patterns were closer to pre-pandemic levels 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 of that demand came from residential buildings. Given that load shapes of residential and commercial buildings are different, this change 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 peak demand, and thus potential to reduce demand, may be higher in residential buildings with more people working from 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 and Its Members?

For ASHRAE members, the impacts of greater instances of working from home will affect them both personally and as part of the business of the Society. For those who are spending more time at home, ASHRAE resources such as the *ASHRAE Standard 62.2 User Manual*[25] or the residential content from the Epidemic Task Force may provide guidance on improving IAQ in a workspace. The relative lack of content, however, demonstrates that ASHRAE members have an opportunity to provide better guidance on creating suitable home work environments.

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, 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. Presumably, standards like ASHRAE Standard 62.1 and ASHRAE Standard 55 identify steps to create suitable working environments, and those steps need to be transferred to standards governing residential spaces such as Standard 62.2.

This task is complicated, however, by the fact that some spaces in homes are used for multiple purposes, e.g., work, sleep, learning. ASHRAE will need to consider the appropriateness of standards that have historically been classified as residential when homes are used more frequently for office work and reassess their scope.

A related societal issue that may impact ASHRAE is the responsibility of employers to ensure adequate workspaces for employees. Many agreements for working from home and training resources stress the need for employees to create ergonomic workspaces. Since research suggests a correlation between the environment and productivity, ASHRAE may be in a position to create guidance for employers and employees on creating workspaces having good IEQ.

The altered use of homes will also impact some of ASHRAE's technical activities. Previous assumptions on occupancy that are presented in the *ASHRAE Handbook*, used in ASHRAE research to evaluate technologies and considered in standards for assessment of building and equipment performance may need to be reconsidered. Additionally, expanded use of homes distributed across a region throughout the day may necessitate greater focus on energy efficiency of residential buildings versus centralized commercial buildings to meet the world's efficiency goals. ASHRAE could play a role in providing guidance on achieving such gains. With ASHRAE striving to enable the decarbonization of the building stock, different use of residential buildings will affect control approaches to align energy use in homes with times when the grid is at its lowest carbon intensity.

The ability to effectively work from home necessitated by the pandemic response has changed where many people will work going forward. Consideration must now be given to ensuring that the environment in residences is conducive to productive work and that residential buildings can adapt to these changes.

References

1. U.S. Census Bureau. 2022. "The Number of People Primarily Working From Home Tripled Between 2019 and 2021." U.S. Census Bureau. http://tinyurl.com/3xeh2xwf

2. Milasi, S., I. Gonzalez-Vazquez, E. 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. http://tinyurl.com/3vj5h9bx

3. Barrero, J., N. Bloom, S. Davis. 2021. "Why Working from Home Will Stick." Working Paper. Working Paper Series. National Bureau of Economic Research. https://doi.org/10.3386/w28731

4. McKinsey & Company. 2022. "Americans are Embracing Flexible Work—and They Want More of It." 2022. McKinsey & Company. http://tinyurl.com/knn62p23

5. Barrero, J, N. Bloom, S. Davis. 2022. "U.S. Survey of Working Arrangements and Attitudes (SWAA)." 2022. https://wfhresearch.com/data

6. Tavares, A. 2017. "Telework and health effects review." *International Journal of Healthcare* 3(2):30. https://doi.org/10.5430/ijh.v3n2p30

7. Montreuil, S., K. 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

8. Cuerdo-Vilches, T., M. Ángel Navas-Martín, S. March, I. Oteiza. 2021. "Adequacy of telework spaces in homes during the lockdown in Madrid, according to socioeconomic factors and home features." *Sustainable Cities and Society* 75:103262. https://doi.org/10.1016/j.scs.2021.103262

9. Xiao, Y., B. Becerik-Gerber, G. Lucas, 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

10. Roh, T., A. Moreno-Rangel, J. Baek, A. Obeng, et al. 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

11. Sun, L., L. 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

12. Singer, B., R. Pass, W. Delp, D. Lorenzetti, et al. 2017. "Pollutant concentrations and emission rates from natural gas cooking burners without and with range hood exhaust in nine California homes." *Building and Environment* 122:215–29. https://doi.org/10.1016/j.buildenv.2017.06.021

13. Mitra, D. Y. Chu, K. Cetin. 2022. "COVID-19 impacts on residential occupancy schedules and activities in U.S. homes in 2020 using ATUS." *Applied Energy* 324:119765. https://doi.org/10.1016/j.apenergy.2022.119765

14. Sarnosky, K., M. Benden, L. Cizmas, A. Regan, et al. 2021. "Remote work and the environment: exploratory analysis of indoor air quality of commercial offices and the home office." Research Square. February. Preprint. https://doi.org/10.21203/rs.3.rs-146008/v1

15. Pietrogrande, M., L. Casari, G. Demaria, M. 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

16. Justo Alonso, M., T. Moazami, P. Liu, R. Jørgensen, et al. 2022. "Assessing the indoor air quality and their predictor variable in 21 home offices during the COVID-19 pandemic in Norway." *Building and Environment* 225:109580. https://doi.org/10.1016/j.buildenv.2022.109580

17. Abelmann, A., A. McEwen, J. Lotter, J. Maskrey. 2020. "Survey of 24-h personal formaldehyde exposures in geographically distributed urban office workers in the USA." *Environmental Science and Pollution Research* 27:17250–57. https://doi.org/10.1007/s11356-020-08218-0.

18. ANSI/ASHRAE Standard 62.2-2022, "Ventilation and Acceptable Indoor Air Quality in Residential Buildings."

19. European Committee for Standardization. 2019. "EN 16798-1:2019: Energy Performance of Buildings–Ventilation for Buildings–Part 1: Indoor Environmental Input Parameters for Design and Assessment of Energy Performance of Buildings Addressing Indoor Air Quality, Thermal Environment, Lighting and Acoustics."

20. Kawka, E., K. Cetin. 2021. "Impacts of COVID-19 on residential building energy use and performance." *Building and Environment* 205:108200. https://doi.org/10.1016/j.buildenv.2021.108200

21. Li, L., C. Meinrenken, V. Modi, P. Culligan. 2021. "Impacts of COVID-19 related stay-at-home restrictions on residential electricity use and implications for future grid stability." *Energy and Buildings* 251:111330. https://doi.org/10.1016/j.enbuild.2021.111330

22. Burleyson, C., A. Rahman, J. Rice, A. Smith, et al. 2021. "Multiscale effects masked the impact of the COVID-19 pandemic on electricity demand in the United States." *Applied Energy* 304:117711. https://doi.org/10.1016/j.apenergy.2021.117711

23. Deiss, B., M. Herishko, L. Wright, M. Maliborska, et al. 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.

24. Krarti, M., M. Aldubyan. 2021. "Review analysis of COVID-19 impact on electricity demand for residential buildings." *Renewable and Sustainable Energy Reviews* 143:110888. https://doi.org/10.1016/j.rser.2021.110888

25. ASHRAE. 2021. *ASHRAE Standard 62.2 User's Manual*. Atlanta. ■