Estimated Ventilation Rates and their Effect on Sleep Quality in Healthy, Young Adults

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INTRODUCTION: Achieving an adequate amount of good-quality sleep is essential for human health and well-being as it affects physiological processes, emotion regulation, physical development, quality of life, and next-day performance. Environmental factors such as light, noise, and thermal comfort have all received significant attention in regard to their effects on sleep quality, but indoor air quality (IAQ) represents another import environmental parameter that has only recently garnered attention. Advances in affordable sensing technology now allow researchers to more easily distribute both IAQ and sleep monitoring devices to a wide array of participants in their home environments, helping to provide more appropriately gathered data from longer study periods that impose less burden on the participant.

In this study, we use affordable sensors to monitor the carbon dioxide (CO_2) concentration in 20 apartment dwellings in Austin, TX over a period of 2.5 months in the summer of 2020. Occupants of these homes were provided a wearable fitness tracker and asked to complete regularly scheduled sleep surveys to measure sleep quality. The CO_2 concentrations were used to estimate the ventilation rates in the participants' bedrooms to assess the relationships between ventilation and a range of sleep quality metrics.

METHODS: Twenty undergraduate students from the University of Texas at Austin were recruited virtually in May of 2020 and provided with a Building EnVironment and Occupancy (BEVO) Beacon and Fitbit Inspire HR™ to monitor their IAQ and sleep quality, respectively. Participants also registered their smartphones with an app that allowed researchers to gather data from a variety of the smartphone sensors and send them sleep quality surveys four times a week at 9:00 am. By June 15th, all participants had received their devices and we asked to keep them on or operating until September 1st when they shipped materials back to the university.

The BEVO Beacon provides IAQ monitoring of multiple, common air pollutants, but we focus on the CO_2 measurements since these concentrations can be used to determine ventilation rates that serve as proxies for overall IAQ. Ventilation rates were estimated in one of two ways based on the principles of a single-zone mass balance. The first method requires periods of a nearly constant CO_2 concentration which allows one to simplify the single-zone mass balance and solve for the ventilation rate directly. The second method assumes the occupant, and therefore the source of CO_2, has left the room. Using an iterative approach, one modifies the ventilation rate in the single-zone mass balance until the values provided by the equation are nearly identical to those measured by the device. In either case, the emission rate of CO_2 from exhaled breath has to be estimated and certain parameters assumed, such as an outdoor CO_2 concentration and well-mixed conditions indoors.

RESULTS AND DISCUSSION: Preliminary results indicate that ventilation rates have an effect on components of both Fitbit-monitored and self-report sleep quality. Figure 1a shows that when ventilation rates are greater than the recommended 0.35 ACH (ASHRAE, 2019), the Total Sleep Time (TST) of individuals is greater than when ventilation is inadequate. The p-value indicates a statistically significant difference between mean TST from each distribution. Figure 1b highlights that participants are more likely to rate their restfulness as positive when the ventilation rate is higher. Performing a t-Test on the mean ventilation rates between the two distributions shows a statistically significant difference.

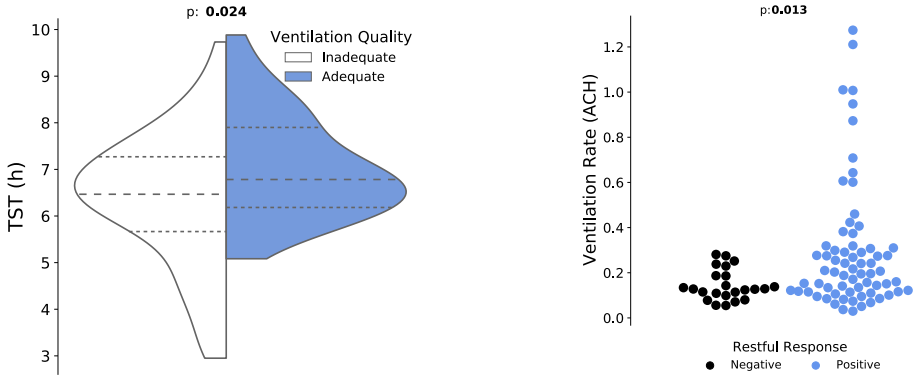

Figure 1. (a) Differences in Fitbit-measured Total Sleep Time (TST) distributions for evenings when ventilation rates are adequate (> 0.35 ACH) or inadequate.
(b) Estimated ventilation rates during evenings separated by nights when participants rate their restfulness as either negative or positive.

These findings mirror results found in related studies that addressed the effects of CO_2 and ventilation on sleep quality parameters. In a field study, Mishra et al. (2018) modulated ventilation by opening or closing windows and doors and found significant differences in the device-measured sleep phase and self-reported depth of sleep between ventilation conditions. Xu et al. (2020) controlled three levels of CO_2 concentrations in laboratory chambers decorated as bedrooms and found that participants took longer to fall asleep and had less short-wave sleep at higher CO_2 concentrations.

CONCLUSIONS: Affordable sensing technologies for IAQ and sleep quality can provide valuable insight into how ventilation can alter sleep quality. These devices also allow researchers to monitor participants in their typical environment, removing any biases associated with acclimating one's sleep to a new environment and traditional, bulky monitors. This study utilizes these devices to highlight how proper ventilation can lead to a longer, more restful sleep.

REFERENCES:

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