In 2015, Carreño et al. [39] provided a review of papers on ventilation in homes and health. Eight papers addressing ventilation rates and health in home were considered. Among these eight papers, four reported improvements in health symptoms, and one reported fewer self-reported common colds, with higher ventilation rates. Because considerable new research has since been published, an updated review of this topic was performed for this web site.

Twenty studies, some reported in more than a single paper, were identified that were published in refereed archival journals and that provided data on the relationships of ventilation rates in homes with the health of the occupants of the homes. Excluded from consideration were studies [58, 59] with occupants moving from an older home to a newer home with a higher ventilation rate, because in these studies many factors other than ventilation rates may have changed. Also excluded were studies of health changes associated with changes in ventilation rates together with simultaneous changes in other factors affecting indoor air quality, such as addition of high efficiency particle filtration or air conditioning, because these studies did not isolate the effects of ventilation rates. However, studies were considered that increased ventilation rates and incorporated simultaneous exposure control measures (such as mattress covers intended to reduce health risks of dust mites) if the study had control homes or control periods that also incorporated the added control measures.

This summary considers six cross sectional studies [60-65], six case-control studies [66-73], and eight intervention studies [74-81]. The cross sectional studies used data from sets of homes chosen without consideration of occupant health status or home ventilation rates. All these studies employed statistical models to quantify the effects of ventilation rates on health, isolated to the extent possible from the effects of other factors, called potential confounders. The potential confounders are features of the homes or occupants potentially correlated with ventilation rates with the potential to influence the health effects. Because of the possibility for residual confounding, i.e., inability to fully isolate the effects of ventilation rates on health from the effects of other factors on health, these cross sectional studies can identify associations but cannot prove causal relationships. The case-
control studies were similar, but were based on case subjects with specific types of adverse health effects and control subjects without these health effects that were otherwise similar to the case subjects. The case control design increases study power and the matching of cases with controls can reduce the potential for confounding error. All but one of the case control studies employed statistical models to quantify the effects of ventilation rates on health, isolated to the extent possible from the effects of potential confounders. Generally, the models used to analyze the results of cross sectional and case control studies adjusted for a broad set of potential confounders. The intervention studies assessed changes in health within the occupants of homes when ventilation rates were intentionally changed. Some intervention studies included periods of real and placebo (fake) increases in ventilation rates within homes, making the occupants unaware of when ventilation rates were actually increased. Some of the intervention studies incorporated sets of control homes and control subjects with placebo increases in ventilation rates. In these studies, changes in health among subjects with real increases in ventilation rates were compared to changes in health among subjects with placebo increases in ventilation rates. The intervention study designs minimize the potential for error caused by uncontrolled confounding.

Overall, 11 of 20 studies [60, 61, 63, 65, 68, 69, 71, 73, 77-79, 81] reported a statistically significant improvement in one or more health outcomes with increased ventilation rates or with lower CO₂ concentrations which indicate higher ventilation rates. Most of these studies included assessments of additional health outcomes that were not statistically significantly associated with ventilation rates. Several studies [62, 72, 74, 75, 78] had notable improvements in health outcomes with higher ventilation rates, but the improvements were not statistically significant. Two studies [66, 69] reported that low ventilation rates increased the health risks of mold, dampness, environmental tobacco smoke or other building factors. One study [64] had a contrary finding, a lower prevalence of diagnosed asthma in homes with higher CO₂ concentrations. One study focusing primarily on how bedroom ventilation affected sleep [80] also reported contrary findings – worsening of mouth and lip dryness when mechanical ventilation was added to bedrooms.

In seven of eight intervention studies, the health effects of occupants of homes were assessed before and after adding a mechanical ventilation system [74, 75, 77-81]. One intervention study [76] assessed health effects before and after small reductions in the rates of ventilation provided by preexisting mechanical ventilation systems. Two intervention studies [79, 81] had no placebos. In these two studies, changes in health among occupants of homes with added mechanical ventilation were compared to changes in health among occupants of homes with no added mechanical ventilation and with no placebo mechanical ventilation. Overall, four of seven intervention studies [77-79, 81] reported statistically significant improvements in one or more health outcomes with increased ventilation rates, although in three of these studies there were no statistically significant improvements in other measured health outcomes. One of the seven studies with an added mechanical ventilation system [75] reported an improvement in bronchial hyper responsiveness that was nearly statistically significant (p = 0.085). In another study [74], approximately 80% of subjects with added mechanical ventilation plus carpet cleaning plus new bedding had improved asthma versus 40% of subjects having improved asthma with carpet cleaning, new bedding, and placebo mechanical ventilation, but this difference was not statistically significant. The intervention study [76] with decreases in the ventilation rates provided by existing mechanical ventilation systems reported no statistically significant changes in health symptoms, but ventilation rates were decreased by only about 9%. An intervention study with added bedroom ventilation [80] had a contrary finding -- a statistically significant worsening of mouth and lip dryness shortly after waking when mechanical ventilation was provided.

Three of the intervention studies [74, 75, 78] were designed to determine whether adding mechanical ventilation to homes in the United Kingdom would improve health of asthmatics sensitive to dust mite allergens by reducing indoor humidity and, in turn, reducing indoor levels of house dust mites. In one of three studies [78], there was a statistically significant improvement in at least one health outcome with added mechanical ventilation.

Considering all of the studies, the amount by which changes in ventilation rates in homes affected health outcomes varied widely among studies. One study [60] reported a nearly 20 fold increase in nocturnal breathlessness with increases in indoor CO₂ concentrations, but the confidence limits for this estimate (2.7 – 146) covered a very wide range indicating a high uncertainty. Another study [61] reported a doubling of respiratory
tract infections with each 500 ppm increase in indoor CO₂ concentrations and a third study [77] reported an 80% reduction in rhinitis with addition of mechanical ventilation. However, other studies [79, 81] reported relatively small magnitude, about 20%, statistically significant changes in health outcomes with a change in ventilation rate.

Many of the studies included several health outcomes and statistically tested for associations of each health outcome with ventilation rate. On average, for every 20 statistical tests, one statistically significant association (5%) will be identified that is merely a chance association. Half of these chance associations (2.5%) would be expected to indicate an improvement in health with increased ventilation rate. Thus, it is important to determine if the number of reported statistically significant improvements in health outcomes with increased ventilation rates exceeded the expected number of expected chance improvements in health. The 20 studies performed approximately 175 statistical tests of associations of ventilation rates with health outcomes excluding mental health outcomes and other outcomes, such as injury, for which there is little reason to anticipate an effect of ventilation rate. Thus, we would anticipate about four chance findings (2.5% of 160 tests) of statistically significant improvements in health with increased ventilation rate while the studies report 24 findings of improvements in health. Also, we would anticipate approximately four chance findings of statistically significant worsening in health with increased ventilation rate which compares to three reported findings. This analysis indicates that the reported number of improvements in health with increased ventilation rate far exceed the expected number of chance improvements.

The studies employed a wide range of ventilation rate metrics in the statistical analyses of health risks. Examples included analyses of health risks: 1) with the ventilation rate or carbon dioxide above or below the median, 2) with an indoor carbon dioxide concentration above or below 1000 ppm, 3) per 500 or 1000 ppm increase in indoor carbon dioxide concentration; 4) per 0.1 h⁻¹ change in ventilation rate, 5) with ventilation rates above versus below 0.5 h⁻¹; 6) with versus without an addition of ~0.17 h⁻¹, 0.4 h⁻¹, or 0.5 h⁻¹ of mechanical ventilation. Possibly because of the wide diversity of metrics, this set of findings provides no clear indication of a threshold ventilation rate below which adverse health effects develop.

In summary, the findings of research on how ventilation rates in homes affect health are mixed. Just over half of studies report one or more statistically significant health benefits of increased ventilation rates. Among studies that report one or more health benefits of increased ventilation rates, in most studies several other measured health outcomes did not improve with increased ventilation rates. Overall, however, the number of reported statistically significant improvements in health with increased ventilation rates far exceeded the anticipated chance improvements in health. The magnitude of the reported statistically significant improvements in health outcomes with increased ventilation rates were highly variable, ranging from 20% to several fold improvements. The research does not identify a threshold ventilation rate below which adverse health effects develop. Much of the published research has investigated the influence of ventilation rates in homes on asthma and related respiratory health outcomes. For other types of health outcomes, little is known about their dependence on home ventilation rates.

In addition to the research findings summarized above, there is indirect evidence that ventilation rates of homes will affect health. From numerous experimental studies, as well as from theoretical modeling, we know that higher ventilation rates will reduce indoor concentrations of a broad range of indoor-generated air pollutants but also increase indoor concentrations of some pollutants from outdoor air. Because exposures to some of the indoor generated air pollutants, for example, environmental tobacco smoke and formaldehyde, have been linked with adverse health [82-85], we expect that increased home ventilation rates will reduce the associated health effects. At the same time, increased home ventilation rates will increase indoor concentrations of particles from outdoor air which are known to adversely affect health. The optimal ventilation rate for overall health will depend on the levels of outdoor air pollutants, the strength of indoor pollutant sources, and the extent to which incoming outdoor air and recirculated indoor air is filtered to remove air pollutants [86]. Ventilation alone cannot optimize health conditions in homes – indoor pollutant sources should be minimized and efficient filtration systems, at least for particles, should be employed.