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Cost-Benefit Analysis of ASHRAE Standard 241

BY RICHARD BRUNS, PH.D.

The risk assessment committee for ASHRAE Standard 241, *Control of Infectious Aerosols*, produced a model to predict the reduction in infections as airflow increased. But what are the estimated costs and benefits of operating in Standard 241's infection risk management mode (IRMM), which is "the mode of operation in which measures to reduce infectious aerosol exposure documented in a building readiness plan are active"? I extended the model to find out.

Because I did not have time or resources to do a detailed cost analysis for each space type, I aimed for a reasonable high cost estimate. Based on discussions with engineers on the committee, I used a standard cost estimate of about $1 per year per additional cfm of clean air required for operating Standard 241's infection risk management mode (IRMM) for four months. This value includes the cost of an HVAC upgrade or commercial-grade air purifier amortized over seven years, plus labor and material operation and maintenance costs, filter replacement and electricity, including the social cost of carbon emissions generated by electricity production, valued at $260/ton ($0.11/kWh).[1]

This is likely to be an overestimate for three reasons. First, in many spaces, filter upgrades and recirculation will be able to supply much or all of the required equivalent clean airflow (ECAi) increase, without requiring any increase in outdoor air. Second, meeting the ECAi requirement using ultraviolet germicidal irradiation (UVGI) may have lower costs than increasing ventilation and filtration. Third, building operators can choose to meet Standard 241's per-person airflow rate requirements by reducing occupancy instead of increasing the equivalent clean airflow rate, if that is more profitable. In addition, this cost estimate will be too high for infrequently used places. Although much of the cost estimate is due to equipment installation, variable costs exist that will not be paid when the building is not in operation.

The calculation of monetized benefits was based on an infection risk model used by the risk assessment committee. The committee used the Wells-Riley model to estimate the change in infection probability in each space type as the equivalent clean airflow rate increased, using a procedure similar to Jones, et al.,[2] and Iddon, et al.[3] The number of infectors was generated according to a binomial distribution according to the number of occupants and the community infection rate.

To calculate the expected community infection rate, we assumed future years would be similar to previous respiratory virus seasons. Clarke, et al.,[4] shows that the seroprevalence of infection-induced SARS-CoV-2 antibodies in the U.S. increased by 25% between Dec.

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TABLE 1 Annual costs and COVID-prevention benefits of Standard 241 in model sites.

OCCUPANCY CATEGORY	AREA (ft^2)	DEFAULT OCCUPANCY	RELATIVE RISK	INFECTIONS PREVENTED	MONETIZED VALUE	COST
Correctional Facilities						
Cell Block	1,200	30	56%	11	$20,000	$730
Dayroom	1,000	30	50%	2.6	$4,900	$1,100
Commercial/Retail						
Food and Beverage Facilities	1,000	50	33%	11	$21,000	$2,600
Gym	5,000	180	35%	39	$72,000	$11,000
Office	10,000	50	87%	1.0	$1,900	$500
Retail	10,000	150	60%	12	$22,000	$4,500
Transportation Waiting	10,000	100	63%	13	$24,000	$5,300
Educational Facilities						
Classroom	1,200	30	59%	3.8	$7,000	$820
Lecture Hall	2,000	150	26%	13	$25,000	$7,500
Industrial						
Manufacturing	10,000	70	93%	0.7	$1,300	$870
Sorting, Packing, Light Assembly	1,000	20	89%	0.6	$1,100	$210
Warehouse	1,000	20	89%	0.6	$1,100	$210
Health Care						
Exam Room	150	3	66%	1.3	$2,500	$55
Group Treatment Area	1,000	20	39%	6.1	$11,000	$1,000
Patient Room	300	3	68%	1.2	$2,200	$99
Resident Room	300	3	82%	0.4	$680	$23
Waiting Room	1,000	30	25%	33	$62,000	$2,100
Public Assembly/Sports & Entertainment						
Auditorium	2,000	150	26%	13	$25,000	$7,500
Place of Religious Worship	2,000	180	27%	4.8	$9,000	$8,700
Museum	10,000	400	34%	27	$51,000	$21,000
Convention	10,000	400	34%	27	$51,000	$21,000
Spectator Area	3,000	100	56%	4.2	$7,900	$4,800
Residential						
Common Space	1,200	12	90%	0.6	$1,100	$52
Dwelling Unit	2,000	6	92%	0.6	$1,200	$82

2021 and Feb. 2022. Given that almost all people are infectious for about five days[5] and that the respiratory virus season lasts 112 days, we assume each day about 1% of the population is infectious. We multiplied the per-person per-hour infection probability by the occupancy rate and operation time to find the total infection risk per site under normal operation and Standard 241's IRMM operation.

To improve the accuracy of the cost-benefit analysis, I first multiplied the expected number of infections in some spaces, especially health-care spaces, by a factor of two or three to represent the increased vulnerability of the people in those spaces. Then I calibrated the model results to the American Time Use Survey, which lists the amount of time the average person spends on activities in the average day. I applied an adjustment factor to adjust the model output, so a person spending the average amount of time in each space, without IRMM operation, has a 25% chance of being infected.

I put a dollar value on the infection reduction using the U.S. Department of Health and Human Services' methodology for public health regulations,[6] which values each life-year gained at about $500,000. Briggs, et al.,[7] shows that an average death causes about eight life-years to be lost, so the value of preventing a death is $4 million.

To calculate the expected future infection fatality rate, I assumed future deaths would be similar to the 2022–2023 virus season, when roughly 30,000 Americans died of COVID.[8] With 25% of the U.S. population infected and 30,000 dying, the infection fatality rate is 0.04%.

Counting only the fatality-reduction benefit, the monetized value of preventing an infection is then about $1,400. To account for nonlethal health effects of an infection, such as the chance of suffering from long COVID, I added $500 to this value, based on the ratio of estimated COVID morbidity and mortality costs.[9] The expected value of preventing an infection is then $1,900.

Table 1 lists estimated costs and monetized COVID-reduction benefits for several model spaces. The areas, ceiling heights and default occupancies of all spaces are taken from ASHRAE Standards 62.1, 62.2 and 170. The additional ECAi required is the difference between the currently required rate and the Standard 241 IRMM rate.

All numbers are rounded to two significant figures.

Given the average daily amount of time Americans spend in various spaces,[10] if every space improved its equivalent clean airflow per person for infection risk mitigation (ECAi) following Standard 241, an average person's risk of catching a respiratory virus via long-range aerosol transmission would decrease by about 25%. If future winters are similar to December 2022 through March 2023, this could prevent about 7,000 COVID deaths annually, in addition to the many other benefits of clean indoor air.

To calculate the total costs, I first estimated the number of these spaces in the U.S. with brief Internet searches of public estimates and then made adjustments to account for occupancy. If all spaces in the U.S. were actually operating at the default occupancy at all times, there would have been many more infections. In reality, some spaces are at their default occupancy, but most have fewer people. Many places with fewer people will already be meeting the required airflow rates and will make no changes, generating no costs or benefits. To account for this, I adjusted the numbers of spaces downward so the number of predicted infections matched the number we observe.

The annual cost of all spaces operating according to Standard 241's IRMM for 16 weeks of the year, during the time of peak respiratory virus transmission in the winter, would be at most \$4 billion. The total monetized COVID-reduction benefit of 16 weeks of IRMM per year is about \$40 billion, about 10 times the total cost. Monetized values of other benefits, such as increased productivity and reduction in other virus infections, would likely be another \$20 billion to \$40 billion.

However, the ratio of costs to benefits is different in different spaces. The risk assessment committee set rates so the absolute per-hour risk in various spaces would be roughly similar. The annual benefits are based on the per-hour risk reduction, multiplied by the expected number of hours per year people will be in the space when it is operating in IRMM. Infrequently used spaces will have relatively lower benefits compared to costs, although as noted above the costs are likely to be overestimated for these spaces. Additionally, manufacturing spaces are the most sparsely populated, and require much more volume of air per person protected, which lowers the benefit/cost ratio.

Much of the annual benefit comes from residential dwelling units. Even though the risk reduction is only about 8%, many units nationwide have six or more occupants, and a large fraction of disease spread happens in homes. Upgrading home air filters to MERV 13 or better and circulating air through them, especially in the winter virus season, is a very cost-effective public health measure.

Despite large benefits, these costs may appear high in many spaces. I argue we should adjust our expectations of what systems are needed and what costs should be paid. Historically, airflow rates have been set at the minimum required for comfort, with no regard for benefits of preventing infection. Additionally, in recent years we have learned the chronic harm of air pollution, especially fine particulates, is much higher than previously estimated. People's expectations of system capacity and costs are not well-calibrated to what is needed to offer even a minimal level of protection to people in indoor spaces.

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