A Cost-Benefit Analysis of CalSHAPE School HVAC Upgrades

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Summary

The monetized social benefits for school HVAC repairs, replacements, and upgrades funded by the California Schools Healthy Air, Plumbing, and Efficiency (CalSHAPE) grant program are, on average, 30 times the costs, with a 90% confidence interval of 7 to 73 times:

Per Student, 2025 USD	CalSHAPE Upgrades		
20-year NPV at 3.1%	**Mean**	5%	95%
Cost	**$2,300**	$2,000	$2,600
Infections Prevented	**$3,800**	$1,600	$7,500
Secondary Transmission	**$16,000**	$7,000	$29,000
Improved Education	**$46,000**	$1,900	$130,000
Asthma Averted	**$2,300**	$560	$5,200
Total benefits	***$68,000***	*$16,000*	*$170,000*
Net benefits	**$65,000**	**$14,000**	**$160,000**
Benefit-cost ratio	**30**	7.0	73

The benefits are mainly driven by educational improvements. HVAC upgrades will improve classroom air quality by removing pollutants, thereby improving test scores, and by extension, future earnings. Temperature regulation should provide additional educational benefits, though the effect is harder to quantify.

Another major effect is the monetized value of reduced secondary transmission of infections. Well-functioning HVAC systems with higher-efficiency filters remove infectious particles, resulting in fewer students getting sick, and fewer members of their communities getting sick and suffering serious complications.

Even without either of these effects, HVAC upgrades still pass a cost-benefit test on average, driven by the two smaller effects of reduced asthma and infections in children.

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Approach, Methodology, Terminology

We analyze CalSHAPE from the point of view of all residents of California collectively. We address the question of whether the health and educational benefits of the HVAC upgrades the program funds justify the capital expenditures. We use as a baseline the grant amount and enrollment data for 172 school sites that received funding to complete HVAC repairs, replacements, and upgrades recommended by a licensed professional after comprehensive HVAC assessments. Given program guidelines, we assume that future funded HVAC upgrades will not significantly differ in price from this baseline. We follow the guidelines and principles in OMB Circular A-94 and the American Institutes for Research Standards for the Economic Evaluation of Educational and Social Programs.[2]

We convert social benefits to their monetary equivalent. We use current HHS values for health benefits. These values come from looking at the choices people make when making tradeoffs between health and money. When we report monetized benefits, this does not mean economic impacts. It means our best estimate of the amount of money that people would be willing to pay to make themselves and their families and communities healthier.

For example, uncontrolled asthma causes people to suffer a Disability Weight of 0.13. The value of one year of healthy life is about $700,000. Therefore, the monetized health value of stopping one child from suffering uncontrolled asthma for one year is about $90,000. When combined with the medical costs of asthma of $8,000 per year, the total value of preventing uncontrolled asthma is $98,000 per year.

For educational benefits, we estimate the present value of improved lifetime earnings.

We focus on those benefits supported by the current literature. Our analysis may therefore understate the true total benefits of HVAC upgrades. For example, we do not model the benefits of reducing acute respiratory infections or post-acute sequelae in teachers. Recent evidence (e.g., Brannock et al.) suggests that COVID-19 reinfections generate significant risk of long COVID. While the data is recent and the science is not yet settled, the benefits of avoiding associated lost work and disability costs are likely to be large.

This analysis is not a state government budget analysis, and makes no attempt to model statewide economic, employment, or trade effects. Notably, it does not attempt to calculate greenhouse gas reductions, which have previously been estimated by the California Air Resources Board (CARB) to be 3,303 MTCO2e for an 18-school subset of the baseline 172 school sites, which received CalSHAPE grants funded through California Climate Investments. Nor does it consider the potential benefits of HVAC upgrades from the point of view of individual schools or school districts that might see, for example, increased funding, engagement, or other benefits due to reduced student and staff absences.

[2] We use a 3.1% discount rate as a default per OMB Circular A-94, Appendix D, and consistent with both frameworks. For reference, results are also presented at a more conservative 7% discount rate.

This analysis also makes no attempt to model the current incidence of the energy efficiency budget contributions, from 2021-2023, used to fund CalSHAPE. According to a recent legislative analysis, if $194 million in unspent program funds revert to contributing investor-owned utilities (IOUs), they could yield savings of “$2 per month for one year for San Diego Gas & Electric ratepayers, $1.25 per month for one year for SoCal Edison ratepayers, and $0.20 per month for one year for Pacific Gas & Electric ratepayers.” However, statute does not require that reverted CalSHAPE funds be refunded to ratepayers or that they be used by IOUs for any other specified purpose.

We used a Monte Carlo simulation to carry through and report uncertainty. Most calculation inputs were in the form of probability distributions rather than point estimates. Throughout the text of the report, we report results as ranges. This is the 90% confidence interval, i.e., the 5th and 95th percentile values from the Monte Carlo simulation. All figures are rounded to two significant figures for readability and to avoid false precision.

Whenever possible, we used data from California. However, in many cases it was necessary to use values from research in other jurisdictions, and in some cases we applied expert judgment based on our understanding of the overall literature.

All monetary values are 2025 USD, abbreviated as $, unless otherwise specified.

In the interest of transparency and accessibility, we did all calculations on a Google Sheet, which is available here for anyone to view and copy. No coding knowledge beyond intermediate spreadsheet proficiency is required to audit, edit, replicate, and extend the calculations:

CBA CalShape Upgrades

We analyzed all costs and benefits over a 20-year time horizon, assuming that HVAC systems last at least that long before requiring significant upgrades or renovation.

We present all values per student. To find the values per school or district, multiply by its average annual number of students.

Key terms and abbreviations used in the report:
ARI: Acute Respiratory Infection
DALY: Disability Adjusted Life Year
HVAC: Heating, Ventilation, and Air Conditioning. A system that filters and conditions outside or recirculated air and delivers it to the classroom
MERV: Minimum Efficiency Reporting Value. MERV is a standardized rating system for how efficiently HVAC filters remove particles from air. The higher the value on the rating scale of 1 to 16, the higher the efficiency of the filter
NPV: Net Present Value
PM: Particulate Matter

1: Description of the Program

The California Schools Healthy Air, Plumbing, and Efficiency (CalSHAPE) grant program was created by AB 841 (2020) to provide 100% grant funding to help make California schools–especially those in underserved and fenceline communities–more energy efficient, healthy, and resilient.[3] The program's funds primarily come from contributions from the energy efficiency budgets of investor-owned utilities (IOUs) over a defined 3-year period that ended in 2023.[4] Under current statute, the program is scheduled to sunset on January 1, 2027, with unspent funds reverting to contributing IOUs on December 1, 2026.

By current statutory formula, 75% of program funds go toward ventilation-related projects, 25% of funds toward plumbing-related projects. While the ventilation program has a pathway for schools without HVAC, to date, all awards have gone to schools with HVAC.

School sites are initially granted funds to conduct comprehensive HVAC system assessments and maintenance, adopt MERV 13 filters where feasible, and install classroom carbon dioxide (CO2) sensors. These Phase 1, Assessment and Maintenance (A&M) grant awards include a 20% "contingency" top-off for minor HVAC repairs. Follow-on Phase 2, Upgrade and Repair (U&R) grant awards, are available for serious repairs, replacements, and upgrades recommended by a licensed professional based on the preliminary HVAC system assessments. Program guidelines define acceptable Phase 2 project parameters, including that all electric equipment must ordinarily be used.

Due to an attempt to repurpose program funds, CalSHAPE applications were closed with little notice in mid-2024 and have never reopened, leaving an estimated $194 million in unspent funds. As a result, of the more than 4,500 schools that received grant awards to conduct initial HVAC assessments, only 172 have been able to obtain follow-on funding to complete recommended repairs, replacements, and upgrades.

We therefore focus our analysis on the benefits of completing serious repairs, replacements, and upgrades recommended by a licensed professional based on comprehensive HVAC system assessments, assuming that, consistent with program guidelines, future grant awards for this work will be similar to those to date.

2: Costs

CalSHAPE has so far awarded about $140 million in Phase 2 grants to 172 schools with enrollments totaling about 100,000 students. Details can be found here:

CalSHAPE Phase 2 School Grantees + Total Enrollment

We assume that future grants would have about the same cost of $1,400 per student.

In addition to the capital costs, the upgraded HVAC systems have maintenance and operations costs, with enhanced efficiency being counterbalanced by greater

[3] The program's official name is the School Energy Efficiency Stimulus Program, with its ventilation component called the School Reopening Ventilation and Energy Efficiency Verification and Repair Program (SRVEVR) and its plumbing component called the School Noncompliant Plumbing Fixture and Appliance Program (SNPFA). However, CalSHAPE is how it is commonly referred to by the administering agency, the California Energy Commission (CEC), and the public.
[4] A small percentage of funds, $20 million, came from the Greenhouse Gas Reduction Fund through California Climate Investments.

complexity (see generally Hines). We conservatively assume that about 50% of ongoing maintenance and operations costs can be attributed to the requirements of the upgraded system over and above those of the baseline system. The additional cost per student is $39 to $80 per year, with a 20-year NPV of $580 to $1,200. We calculate and report the NPV of costs per student including this increased burden.

3: Benefits

The four key benefits of an HVAC system upgrade are:

1) Decreased respiratory infection among schoolchildren
2) Decreased secondary spread of respiratory infection
3) Improved educational outcomes
4) Decreased asthma among schoolchildren

There are other benefits, such as reduced staff absences, but we focus on the ones that are largest and best supported by the evidence.

We do not have data on the benefits of CalSHAPE Phase 2 grant-funded projects specifically. Therefore, we must extrapolate from the literature on classroom indoor air quality improvements of the type expected with HVAC upgrades based on professional recommendations following initial assessments.

We have data on the effectiveness of in-room air-filtering devices, and of upgrading a system from MERV 8 to 13 filters, which will provide increased protection (equivalent clean airflow) as described in ASHRAE Standard 241. We conservatively estimate that the CalSHAPE upgrades will give about 50% of the benefit of in-room filters.

3.1 Decreased Student Infection

American students have 0.8 to 1.2 acute respiratory infections per 100 enrolled days. 40% to 60% of infections are acquired in schools. The risk of long-range infection is reduced by 30% to 50% with better filtration (Thornton, Pereira). However, we do not know what percentage of infection is due to the long-range transmission route. It could be as low as 30% or as high as 70%, with the remaining infections coming from close contact, which HVAC systems can do little or nothing to prevent.

Therefore, HVAC upgrades will reduce ARI by 0.10 to 0.28 cases per student per year.

3.2 Decreased Secondary Infection

Based on our review of the vaccination modeling literature (e.g., Eichner and Basta) we estimate that each infection prevented in a school child results in 0.5 to 1.5 infections being prevented in the population. Therefore, we expect that secondary infections will be reduced by 0.09 to 0.29 per student per year as a result of HVAC upgrades.

3.3 Improved Education

HVAC upgrades can improve educational outcomes through improved classroom air quality, including cleaner air and better-controlled temperatures.

Air-filtering devices have been shown to improve test scores by 0.1 to 0.2 standard deviations (Gilraine). However, we do not know how permanent this effect is. The test-score effect of air filtration has not been proven to improve future earnings the same way other improvements in test scores do. The test scores could be measuring a permanent improvement in skills, or it could be that the "underlying knowledge" is the same and the air quality only improved test performance. To account for this, we add a factor for the persistence of the effect. This variable is distributed as a beta distribution, from 0 to 1, with parameters $\alpha=1$ and $\beta=4$ (i.e., most probability weight on the low end), for an average value of 19%.

With this estimate, the "permanent" educational attainment increase is 0.001 to 0.04 standard deviations. Each standard deviation improves lifetime earnings by 5% to 11%, so we expect that filtration should improve lifetime earnings by 0.01% to 0.64% each year the student is exposed to it, and the HVAC upgrades (50% as effective) will improve earnings by 0.005% to 0.32%.

Evidence suggests that extreme classroom temperatures negatively impact educational outcomes, with temperatures near 20°C (68°F) perhaps being optimal (Wargocki). A 2020 study of schools across California, with existing but not necessarily well-functioning HVAC systems, found that many classrooms experienced temperatures above 78°F or below 68°F during school hours (Pistochini). Given limited evidence on how upgrades to existing classroom HVAC systems affect test scores, as distinct from new installations in previously unserved classrooms (Park), we treat temperature-related learning improvements as a qualitative co-benefit of HVAC upgrades, likely positive but not reliably quantifiable with current evidence.

3.4 Asthma

The current prevalence of asthma in California school children is 13% to 20% depending on demographics. Every 1 μg/m3 reduction in particulates reduces asthma by 1% to 9%. Children spend about 14% of their time in classrooms, so we assume that classroom particulate levels will have 14% of this effect size. Measurements of California schools with MERV 8 versus MERV 13 filters show the levels of dangerous particulates (PM2.5) being reduced by 2.3 to 4 μg/m3. Therefore we expect that the upgrades will reduce asthma prevalence by 0.1 to 0.5 percentage points.

4: Monetized Benefits

4.1 Decreased Student Infection

Student illness generates costs in the forms of caregiver time, medical bills, lost DALYs, and a very small chance of hospitalization and death. Of these, the largest component is caregiver time. Each infection generates an average of 1 to 2 days of lost work for caregivers (Neuzil, Heikkinen) valued at $450 to $840 per infection. The total monetized cost is $890 to $2,100 per case.

With 0.10 to 0.28 cases prevented per student per year, the annual benefits are valued at $110 to $500 per student.

4.2 Decreased Secondary Infection

Older people are much more likely than children to suffer serious complications and death from infection. Molinari et al. estimate average total costs, including monetized life and health losses, for US influenza cases. We convert their 2007 USD value to 2025 USD and estimate that each community case has an expected harm of $3,900 to $8,200.

With 0.09 to 0.29 secondary cases prevented per student per year, the annual benefits are valued at $470 to $2,000 per student.

4.3 Improved Education

To value an increase in lifetime earnings, we must first estimate their net present value. Our procedure is:

1) Assume students start earning income 15 years on average after being exposed to better air quality, and that they then work for 40 years.
2) Assume that annual incomes grow at the same rate as GDP per capita. The 10-year average of GDP growth is about 1.8%.
3) Calculate the NPV of 40 years of income, growing at the indicated rate, discounted at 3.1%.
4) Discount that value back another 15 years to the present day.

This results in a discounted average lifetime income of $2.2 to $3.2 million. The educational gain from the upgrades then has an expected value of $130 to $8,900 per student per year.

4.4 Asthma

The costs of asthma include medical costs, caregiver time, and the DALY loss, i.e., pain and suffering. Of these, the monetized DALY loss dominates the calculation. The disability weight of asthma is 0.015 to 0.133 and the total monetized cost of a case is $21k to $93k per year.

We assume that the duration of asthma is the time in school; if classroom exposure caused a longer duration of asthma that persisted after leaving the school environment, the cost would be much higher than we estimate here.

Given the prevalence change caused by HVAC upgrades, their annual asthma-prevention value is $38 to $360 per student.

5: Calculate Net Present Value

We discount all future annual values and add them up to calculate the 20-year NPV at a 3.1% discount rate[5]:

Per Student, 2025 USD	CalSHAPE Upgrades		
20-year NPV at 3.1%	**Mean**	5%	95%
Cost	**$2,300**	$2,000	$2,600
Infections Prevented	**$3,800**	$1,600	$7,500
Secondary Transmission	**$16,000**	$7,000	$29,000
Improved Education	**$46,000**	$1,900	$130,000
Asthma Averted	**$2,300**	$560	$5,200
Total benefits	***$68,000***	*$16,000*	*$170,000*
Net benefits	**$65,000**	**$14,000**	**$160,000**
Benefit-cost ratio	**30**	7.0	73

We also present the numbers at a 7% discount rate:

Per Student, 2025 USD	CalSHAPE Upgrades		
20-year NPV at 7%	**Mean**	5%	95%
Cost	**$2,000**	$1,800	$2,300
Infections Prevented	**$2,800**	$1,200	$5,400
Secondary Transmission	**$11,000**	$5,000	$21,000
Improved Education	**$10,000**	$430	$29,000
Asthma Averted	**$1,700**	$410	$3,800
Total benefits	***$26,000***	*$9,500*	*$54,000*
Net benefits	**$24,000**	**$7,500**	**$52,000**
Benefit-cost ratio	**13**	4.8	27

[5] Note: In a Monte Carlo simulation, confidence intervals are not additive. Only the mean values can be summed across rows.

References

Ahmad, K., Khanam, R., Kabir, E., & Jürges, H. (2023). The healthcare cost burden of asthma in children: A longitudinal population-based study. *Value in Health*, *26*(8), 1201–1209. https://doi.org/10.1016/j.jval.2023.04.003

American Institutes for Research. (2021, April). *Standards for the economic evaluation of educational and social programs* (Cost Analysis Standards Project). https://www.air.org/sites/default/files/Standards-for-the-Economic-Evaluation-of-Educational-and-Social-Programs-CASP-May-2021.pdf

American Society of Heating, Refrigerating and Air-Conditioning Engineers. (2023). *ASHRAE Standard 241-2023: Control of infectious aerosols*. https://www.ashrae.org/technical-resources/bookstore/ashrae-standard-241-control-of-infectious-aerosols

American Society of Heating, Refrigerating and Air-Conditioning Engineers. (2025). *ANSI/ASHRAE Standard 52.2-2025: Method of testing general ventilation air-cleaning devices for removal efficiency by particle size*. https://www.ashrae.org/technical-resources/bookstore/ashrae-standard-52-2

Banta, J. E., Ramadan, M., Alhusseini, N., Aloraini, K., & Modeste, N. (2021). Socio-demographics and asthma prevalence, management, and outcomes among children 1–11 years of age in California. *Global Health Research and Policy*, *6*, Article 17. https://link.springer.com/article/10.1186/s41256-021-00199-y

Basta, N. E., Chao, D. L., Halloran, M. E., Matrajt, L., & Longini, I. M. (2009). Strategies for pandemic and seasonal influenza vaccination of schoolchildren in the United States. *American Journal of Epidemiology*, *170*(6), 679–686. https://doi.org/10.1093/aje/kwp237

Brannock, M. D., Hadley, E., Preiss, A., Fitzgerald, M. L., Jain, N., Taylor, E., Wylam, A., Yoo, Y. J., Hill, E., & Moffitt, R. A. (2025). *Incidence of long COVID following reinfection with COVID-19* [Preprint]. *medRxiv*. https://doi.org/10.1101/2025.08.12.25333155

Buonanno, G., Ricolfi, L., Morawska, L., & Stabile, L. (2022). Increasing ventilation reduces SARS-CoV-2 airborne transmission in schools: A retrospective cohort study in Italy's Marche region. *Frontiers in Public Health*, *10*, Article 1087087. https://doi.org/10.3389/fpubh.2022.1087087

Buonanno, G., Stabile, L., & Morawska, L. (2020). Estimation of airborne viral emission: Quanta emission rate of SARS-CoV-2 for infection risk assessment. *Environment International*, *141*, Article 105794. https://doi.org/10.1016/j.envint.2020.105794

Bureau of Labor Statistics. (2026, March 20). *Employer costs for employee compensation – December 2025* (USDL-26-0505). https://www.bls.gov/news.release/pdf/ecec.pdf

California Air Resources Board. (2023, May 31). *Quantification methodology for the California Energy Commission, California Schools Healthy Air, Plumbing, and Efficiency Program, California Climate Investments*. https://ww2.arb.ca.gov/sites/default/files/auction-proceeds/cec_calshape_qm_final_2023.pdf

California Climate Investments. (n.d.). *California Schools Healthy Air, Plumbing, and Efficiency (CalSHAPE) Program*. Retrieved April 28, 2026, from https://www.caclimateinvestments.ca.gov/calshape

California Department of Education. (n.d.). *LCFF & instructional time FAQs*. Retrieved April 28, 2026, from https://www.cde.ca.gov/fg/aa/pa/lcffitfaq.asp

California Energy Commission. (n.d.). *California Schools Healthy Air, Plumbing, and Efficiency (CalSHAPE) Program*. Retrieved April 28, 2026, from https://www.energy.ca.gov/programs-and-topics/programs/california-schools-healthy-air-plumbing-and-efficiency-program

California Energy Commission. (2024a). *California Schools Healthy Air, Plumbing, and Efficiency Ventilation Program guidelines, fifth edition* (Publication No. CEC-300-2024-003). https://www.energy.ca.gov/publications/2024/california-schools-healthy-air-plumbing-and-efficiency-ventilation-program

California Energy Commission. (2024b). *California Schools Healthy Air, Plumbing, and Efficiency Program activities and expenditures: Annual report on program year 2023* [Staff report] (Publication No. CEC-300-2024-001). https://www.energy.ca.gov/publications/2024/california-schools-healthy-air-plumbing-and-efficiency-program-activities-and

California Energy Commission. (2025). *California Schools Healthy Air, Plumbing, and Efficiency Program activities and expenditures: Annual report on program year 2024* [Staff report] (Publication No. CEC-300-2025-003). https://www.energy.ca.gov/publications/2025/california-schools-healthy-air-plumbing-and-efficiency-program-activities-and

California Energy Commission. (n.d.). *CalSHAPE Program grant awarded list* [Data set]. Retrieved February 3, 2026, from https://www.energy.ca.gov/media/6814

California Legislature. (2020). *Assembly Bill 841: Energy: Transportation electrification: Energy efficiency programs: School Energy Efficiency Stimulus Program* (Chapter 372, Statutes of 2020). https://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=201920200AB841

California School Boards Association. (n.d.). *California student-teacher ratio is very high* [Fact sheet]. https://www.csba.org/~/~/media/46DA0EAFE7364D70B541F5950D26DC9A.ashx

California Senate Budget and Fiscal Review Committee. (2026, March 5). *Subcommittee No. 2 on Resources, Environmental Protection and Energy: Agenda* [Hearing record]. https://sbud.senate.ca.gov/system/files/2026-03/sub-2-energy-utilities-agenda-mar-5.pdf

Cal. Pub. Util. Code § 1600 (2020). https://leginfo.legislature.ca.gov/faces/codes_displaySection.xhtml?lawCode=PUC&sectionNum=1600

Cal. Pub. Util. Code § 1615 (2020). https://leginfo.legislature.ca.gov/faces/codes_displaySection.xhtml?lawCode=PUC&sectionNum=1615

Cal. Pub. Util. Code § 1616 (2020). https://leginfo.legislature.ca.gov/faces/codes_displaySection.xhtml?lawCode=PUC&sectionNum=1616

Cal. Pub. Util. Code § 1621 (2020).https://leginfo.legislature.ca.gov/faces/codes_displaySection.xhtml?lawCode=PUC&sectionNum=1621

Education Data Partnership. (n.d.). *Ed-Data: Fiscal, demographic, and performance data on California's K-12 schools* [Database]. Retrieved February 3, 2026, from https://www.ed-data.org/

Eichner, M., Schwehm, M., Eichner, L., & Gerlier, L. (2017). Direct and indirect effects of influenza vaccination. *BMC Infectious Diseases*, *17*, Article 308. https://doi.org/10.1186/s12879-017-2399-4

Endo, A., Uchida, M., Hayashi, N., Liu, Y., Atkins, K. E., Kucharski, A. J., & Funk, S. (2021). Within and between classroom transmission patterns of seasonal influenza among primary school students in Matsumoto city, Japan. *Proceedings of the National Academy of Sciences, 118*(46), Article e2112605118. https://doi.org/10.1073/pnas.2112605118

Gilraine, M. (2023). Air filters, pollution, and student achievement. *Journal of Human Resources*, *60*(5), 1469-1506. https://doi.org/10.3368/jhr.0421-11642R2

Goldman, J. L., Lee, B. R., Almendares, O. M., Kirking, H. L., Derado, G., Banerjee, D., Sasidharan, A., Porter, J., Tilsworth, S., Selvarangan, R., & Schuster, J. E. (2025). Respiratory virus detection and acute respiratory illness rates in students and staff in schools. *Pediatrics, 156*(4), Article e2025070886. https://doi.org/10.1542/peds.2025-070886

Heikkinen, T., Silvennoinen, H., Peltola, V., Ziegler, T., Vainionpää, R., Vuorinen, T., Kainulainen, L., Puhakka, T., Jartti, T., Toikka, P., Lehtinen, P., Routi, T., & Juvén, T. (2004). Burden of influenza in children in the community. *The Journal of Infectious Diseases*, *190*(8), 1369–1373. https://doi.org/10.1086/424527

Hines, E., & Ross, S. (2023, January). *HVAC choices for student health and learning: What policymakers, school leaders, and advocates need to know*. RMI; UndauntedK12. https://rmi.org/insight/hvac-choices-for-student-health-and-learning/

Jones, B. (2024, August 6). Education groups urge Calif. lawmakers to restart school clean air fund. *Politico*. https://www.eenews.net/articles/education-groups-urge-calif-lawmakers-to-restart-school-clean-air-fund/

Kane, T. J., Doty, E., Patterson, T., & Staiger, D. O. (2022). *What do changes in state test scores imply for later life outcomes?* Center for Education Policy Research, Harvard University. https://educationrecoveryscorecard.org/wp-content/uploads/2022/10/Long-Term-Outcomes.pdf

Kearsley, A. (2025, February 13). *HHS standard values for regulatory analysis, 2025* [Data point]. U.S. Department of Health and Human Services, Office of Science and Data Policy. https://aspe.hhs.gov/sites/default/files/documents/639756a60fbe7e51786bcec176ad52f1/Standard-RIA-Values-2025.pdf

Keren, R., Zaoutis, T. E., Saddlemire, S., Luan, X. Q., & Coffin, S. E. (2006). Direct medical cost of influenza-related hospitalizations in children. *Pediatrics*, *118*(5), e1321–e1327. https://doi.org/10.1542/peds.2006-0598

Kim, D. (2025). A nationwide study of risk factors for long COVID and its economic and mental health consequences in the United States. *Communications Medicine*, *5*, Article 104. https://doi.org/10.1038/s43856-025-00759-0

Liu, S., Jørgensen, J. T., Ljungman, P., Pershagen, G., Bellander, T., Leander, K., Magnusson, P. K. E., Rizzuto, D., Hvidtfeldt, U. A., Raaschou-Nielsen, O., Wolf, K., Hoffmann, B., Brunekreef, B., Strak, M., Chen, J., Mehta, A., Atkinson, R. W., Bauwelinck, M., Varraso, R., ... Andersen, Z. J. (2021). Long-term exposure to low-level air pollution and incidence of asthma: The ELAPSE project. *European Respiratory Journal*, *57*(6), Article 2003099. https://doi.org/10.1183/13993003.030992020

Molinari, N.-A. M., Ortega-Sanchez, I. R., Messonnier, M. L., Thompson, W. W., Wortley, P. M., Weintraub, E., & Bridges, C. B. (2007). The annual impact of seasonal influenza in the US: Measuring disease burden and costs. *Vaccine*, *25*(27), 5086–5096. https://doi.org/10.1016/j.vaccine.2007.03.046

National Center for Education Statistics. (n.d.). *Average class size in public schools, by class type and state: 2017–18* [Data table]. National Teacher and Principal Survey. https://nces.ed.gov/surveys/ntps/tables/ntps1718_fltable06_t1s.asp

Neuzil, K. M., Hohlbein, C., & Zhu, Y. (2002). Illness among schoolchildren during influenza season: Effect on school absenteeism, parental absenteeism from work, and secondary illness in families. *Archives of Pediatrics & Adolescent Medicine*, *156*(10), 986–991. https://doi.org/10.1001/archpedi.156.10.986

Office of Management and Budget. (2023a, November 9). *Circular No. A-94: Guidelines and discount rates for benefit-cost analysis of federal programs*. https://www.whitehouse.gov/wp-content/uploads/2023/11/CircularA-94.pdf

Office of Management and Budget. (2023b, November 9). *Circular No. A-94, Appendix D: Discount rates for benefit-cost analysis*. https://www.whitehouse.gov/wp-content/uploads/2023/11/CircularA-94AppendixD.pdf

Park, R. J., Goodman, J., Hurwitz, M., & Smith, J. (2020). Heat and learning. *American Economic Journal: Economic Policy*, *12*(2), 306–339. https://doi.org/10.1257/pol.20180612

Pereira, M., Vilain, R., Tribess, A., & Morawska, L. (2015). Risk assessment for airborne infectious diseases between natural ventilation and a split-system air conditioner in a university classroom [Conference paper]. *Proceedings of the 23rd ABCM International Congress of Mechanical Engineering (COBEM 2015)*, Rio de Janeiro, Brazil. https://web.archive.org/web/20200505101627id_/https://eprints.qut.edu.au/93784/27/93784.pdf

Pistochini, T., Mande, C., Modera, M., Outcault, S., Sanguinetti, A., Chan, W. R., Dutton, S., Singer, B., & Li, X. (2020). *Improving ventilation and indoor environmental quality in California K-12 schools* [Final project report] (Publication No. CEC-500-2020-049). California Energy Commission, Energy Research and Development Division. https://www.energy.ca.gov/sites/default/files/2021-05/CEC-500-2020-049.pdf

Sidecar Health. (n.d.). *Cost of pediatrician visit by state*. Retrieved April 28, 2026, from https://cost.sidecarhealth.com/c/pediatrician-visit-cost

Stabile, L., Buonanno, G., Frattolillo, A., & Dell'Isola, M. (2019). The effect of the ventilation retrofit in a school on CO2, airborne particles, and energy consumptions. *Building and Environment*, *156*, 1–11. https://doi.org/10.1016/j.buildenv.2019.04.001

Stabile, L., Pacitto, A., Mikszewski, A., Morawska, L., & Buonanno, G. (2021). Ventilation procedures to minimize the airborne transmission of viruses in classrooms. *Building and Environment*, *202*, Article 108042. https://doi.org/10.1016/j.buildenv.2021.108042

Thornton, G. M., Fleck, B. A., Kroeker, E., Dandnayak, D., Fleck, N., Zhong, L., & Hartling, L. (2023). The impact of heating, ventilation, and air conditioning design features on the transmission of viruses, including the 2019 novel coronavirus: A systematic review of filtration. *PLOS Global Public Health*, *3*(9), Article e0002389. https://doi.org/10.1371/journal.pgph.0002389

Toelle, B. G., Peat, J. K., Mellis, C. M., & Woolcock, A. J. (1995). The cost of childhood asthma to Australian families. *Pediatric Pulmonology*, *19*(6), 330–335. https://doi.org/10.1002/ppul.1950190604

Wargocki, P., Porras-Salazar, J. A., & Contreras-Espinoza, S. (2019). The relationship between classroom temperature and children's performance in school. *Building and Environment*, *157*, 197–204. https://doi.org/10.1016/j.buildenv.2019.04.046

World Bank Group. (n.d.). *GDP per capita growth (annual %) – United States* [Data set]. Retrieved April 28, 2026, from https://data.worldbank.org/indicator/NY.GDP.PCAP.KD.ZG?locations=US

World Health Organization. (2024, May). *WHO methods and data sources for global burden of disease estimates, 2000–2021* [Technical paper]. https://cdn.who.int/media/docs/default-source/gho-documents/global-health-estimates/ghe2021_daly_methods.pdf