INTRINSIC
Environment, Health & Safety

RE: Classroom Airflow Testing and Analysis for COVID-19 and Wildfire Smoke PM 2.5 Mitigation after HVAC Filter Replacement, Economizer Adjustments

This report presents the findings of our ventilation assessment and analysis of Harmony Union School District ventilation preparedness for COVID-19 and Wildfire PM 2.5 mitigation.

Dear Superintendent-Principal Morgan, and Chief Business Official Kalember,

Saturday March 20th, 2021, Friday March 26th, 2021, and Friday April 20th, 2021 Intrinsic Environment, Health & Safety's Industrial Hygiene and HVAC Team installed upgraded MERV filters, adjusted economizers to maximize outside air, and measured airflow. Airflow data was then analyzed and compared against ASHRAE, CDC, CDPH, County, and best practices guidelines for ventilation. A presentation was provided to HUSD's Board of Education April 15th, 2021. Subseqently additional analysis was performed to evalute preparedness for wildfire PM 2.5 mitigation. This work was an extension of work that began in November of 2020 to assess HUSD's ventilation systems. The purpose of our work was to ensure classroom HVAC systems provide sufficient dilution and filtration ventilation to meet or exceed applicable guidlines. All Harmony Union School District classrooms meet or exceed applicable guidelines for COVID-19 mitigation, and are well prepared for the next wildfire season.

BACKGROUND

As part of HUSD's plan for a return to in-person instruction, HUSD requested Intrinsic EH&S review HUSD's ventilation capabilities for risk reduction for COVID-19 transmission. As part of our scope of work, a representative sample of each of the types of classrooms from Buildings B through F, the Gymnasium, the Assembly Room, Library, select restrooms, and staff break room were included in our initial assessment. The overaching goal was to understand the range of ventilation systems, their respective capabilities, identify issues and opportunities for improvement.

Recommendations from our February 26th, 2021 report were then incoporated into this revised scope of work, which included replacing existing filters with upgraded MERV filters, opening economizers, and measuring airflow. That airflow data was then used to calculate air changes

per hour (ACH), along with cubic feet per minute (cfm) of "Equivalent Outside Air" to quantitatively compare against all applicable guidelines.

METHODOLOGY

Utilzing a calibrated Evergreen Telemetry balometer, and a calibrated TSI VelociCalc with a rotary vane anemometer (RVA), Intrinsic's Occupational Environmental Health Team measured airflow in all classrooms, as well as the Library, Gym, Cafeteria, and Main Offices. Measurements were taken in cubic feet per minute (cfm), unless the RVA used, in which case linear flow was used to determine cfm. All filters had been replaced, economizers opened, and systems were in normal operating status prior to our assessment. Room dimensions were then used to calculate air changes per hour (ACH).

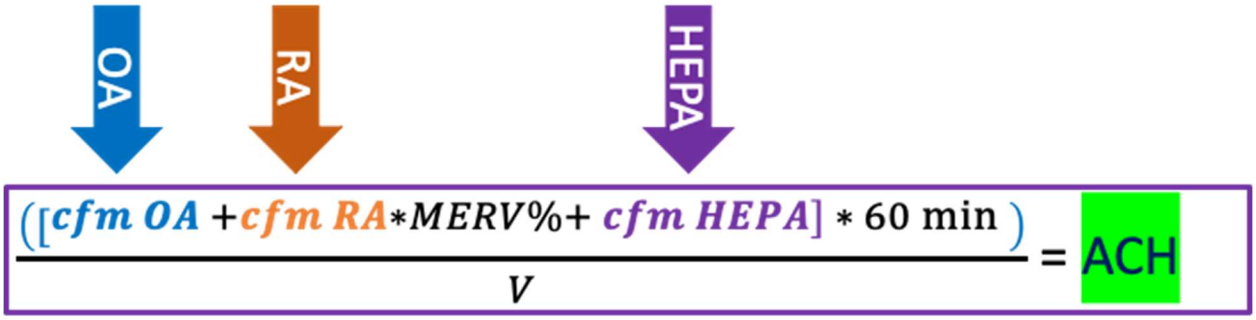
For those spaces that had registers which needed to be measured using the vane anemometer, linear airflow was converted to cfm by multiplying the linear airflow by the dimensions of the register, and incorporating a conservative correction factor of 0.65 to determine cfm.

lfm * width of register * length of register * 0.65 = cfm

Measured cfm values were then subdivided into 2 catagories: outside air (OA) and return air (RA). While those classrooms that have had their economizers open fully should be allowing close to 30% outside air, a more conservative estimate of 20% was selected. The remaining 80% recirculated return air was multiplied by a correction factor, based on the MERV rating of the filter in place. ASHRAE has determined based on current understanding about the distrubution of the virus that filtering air through MERV provides a specific percentage of "Equivalent Outdoor Air".

MERV Rating (Based on 52.2-2017)	Filter Droplet Nuclei Efficiency
4	16.80%
5	26.55%
6	32.45%
7	41.13%
8	55.57%
9	62.00%
10	64.65%
11	72.86%
12	83.39%
13	89.93%
14	94.94%
15	96.18%
16	97.40%

These outside air (OA), and return air (RA) values were then combined with the amount of CADR (clean air deliver rate) of cfm from the HEPA filter. This report includes locations and associated measurements (cfm, and cubic volume) along with calculated air exchange values (ACH) that incorporate the cfm of the HEPA filter for that specific location.



The basis for our assessment, and subsequent recommendations are based on guidance from CDC Guidance for Schools, ASHRAE, California Department of Public Health ANSI/ASHRAE Standard 62.1-2019 summarized below…

- Increase outside air ventilation
- When weather conditions allow, increase fresh outdoor air...Do not open windows and doors if doing so poses a safety or health risk e.g. triggering asthma symptoms
- Use **fans** to increase the effectiveness of open windows. Position fan so as not to induce potentially contaminated airflow directly from one person to another
- Decrease occupancy in areas where outdoor ventilation cannot be increased
- Ensure ventilation systems operate properly and provide acceptable indoor air quality for the current occupancy level for each space
- Increase total airflow supply to occupied spaces
- Disable demand-controlled ventilation (DCV) controls that reduce air supply based on occupancy or temperature during occupied hours, by setting thermostat to Fan On instead of Fan Auto
- Improve central air filtration:
    - Increase air filtration to as high as possible without significantly reducing design airflow.
    - Inspect filter housing and racks to ensure appropriate filter fit and check for ways to minimize filter bypass.
    - Check filters to ensure they are within their service life and appropriately installed
- Ensure restroom exhaust fans are functional and operating at full capacity when the building is occupied.
- Consider installing portable high-efficiency air cleaners

CLASSROOM FINDINGS

With the incorporation of upgraded MERV filters into all classrooms, they now have more than adequate airflow. The IQ*Air* CleanZone SL, within each classroom, provides 820m^3/hr (cubic meters per hour), which equates to approximately 483cfm (cubic feet per minute). Combined with the outside air, and MERV filtration, all of HUSD's classrooms meet the targeted 6 ACH (air changes per hour). COVID-19 Mitigation Mode assumes maximized outside air. Wildfire and COVID-19 Mitigation Mode assumes outside air has been minimized, by closing economizers, to minimize the amount of wildfire smoke, and PM 2.5 in particular, can enter into the classroom. Therefore, calculations are of "Equivalent Outdoor Air" as determined by the MERV and HEPA filtration present in a given space.

Classroom Data:

COVID-19 Mitigation Mode Analysis

Room	Combined ACH	cfm of OA Equivalent above ASHRAE Guidelines for 25 students
Red Alder Room	6.4	112
Coast Live Oak	6.2	113
Redwood	8.3	150
Bay	6.0	110
Dogwood	7.1	127
Maple	7.6	127
Madrone	6.9	80
Buckeye	6.9	80
Hazelnut	9.3	116
Black Hawthorn	8.8	115
Willow	9.1	116
Oregon Ash	9.2	116
Black Oak	10.3	112
Tan Oak	6.6	59
Douglas Fir	10.4	117

Figure 1: COVID-19 Mitigation Mode (maximized outside air), MERV 11/13, HEPA (25 students)

Wildfire and COVID-19 Mitigation Mode Analysis

Room	Combined ACH	cfm of OA Equivalent above ASHRAE Guidelines for 25 students
Red Alder Room	6.1	112
Coast Live Oak	5.9	113
Redwood	8.0	150
Bay	5.7	110
Dogwood	6.8	127
Maple	7.2	127
Madrone	6.9	80
Buckeye	6.9	80
Hazelnut	9.3	116
Black Hawthorn	8.8	115
Willow	9.1	116
Oregon Ash	9.2	116
Black Oak	9.7	112
Tan Oak	6.3	59
Douglas Fir	9.8	117

Figure 2: COVID-19/Wildfire Mitigation Mode (minimized outside air), MERV 11/13, HEPA (25 students)

LIBRARY FINDINGS

Given that the space is a much larger space, even with the assumed four IQ*Air* CleanZone SL's providing 820m^3/hr at max flowrate, economizers opened at full and MERV 11 filters, 6 ACH is likely an unattainable goal. However, ASHRAE recommends 0.12cfm/ft^2 and an additional 5cfm/person for Libraries. Assuming that economizers are open to allow a minimum of 20% OA, this should allow sufficient airflow for a classroom cohort of 25 students, and still meet ASHRAE guidelines. It is still advisable to prevent cohorts from mixing, and allow sufficient time to permit 3 air changes (~1 hour), prior to the next cohort using the same space.

Library Data:

COVID-19 Mitigation Mode Analysis

Room	Combined ACH	cfm of OA Equivalent above ASHRAE Guidelines for 25 students
Library	3.0	1876

Figure 3: COVID-19 Mitigation Mode (maximized outside air), MERV 11, 4 HEPAs (25 students)

Wildfire and COVID-19 Mitigation Mode Analysis

Room	Combined ACH	cfm of OA Equivalent above ASHRAE Guidelines for 25 students
Library	2.9	1818

Figure 4: COVID-19/Wildfire Mitigation Mode (minimized outside air), MERV 11, 4 HEPAs (25 students)

ORACLE OAK ROOM FINDINGS

The Oracle Oak Rooms are used only for staff. Therefore, the minimum ventilation rates for Office Building Breakrooms per ASHRAE 62.1-2019 is a more appropriate metric for comparison. Moreover, there were no HEPA filters noted at the time of our evaluation, so the contribution from HEPA filtration was omitted from our analysis. In order to estimate the number of staff present, a conservative estimate for the max number of people that could be inside the Oracle Room was calculated. Six feet of social distancing was assumed to calculate the square footage

of a circle with a 3ft radius ($A = \pi r^2$). In this case, with a 3ft radius A=28.27sq ft. Dividing the square footage of the room by the area of a circle with 3ft radius we estimate ~15 staff members at a max for the Oracle Oakroom. Likely this is much higher than actual occupancy numbers. Therefore, this is a conservative estimate for calculating cfm of equivalent outside air in excess of ASHRAE Guidelines for staff in an office breakroom.

Oracle Oak Room Data:

COVID-19 Mitigation Mode Analysis

Room	Combined ACH	cfm of OA Equivalent above ASHRAE Guidelines for staff assuming 6' Social Distancing
Oracle Oak Main Entrance	14.7	485
Oracle Oak Bathroom	8.0	84
Oracle Workroom	7.1	365

Figure 5: COVID-19 Mitigation Mode (maximized outside air), MERV 11 (Staff, 6' Social Distancing)

Wildfire and COVID-19 Mitigation Mode Analysis

Room	Combined ACH	cfm of OA Equivalent above ASHRAE Guidelines for staff assuming 6' Social Distancing
Oracle Oak Main Entrance	13.5	441
Oracle Oak Bathroom	7.4	79
Oracle Workroom	6.5	326

Figure 6: COVID-19/Wildfire Mitigation Mode (minimized outside air), MERV 11 (Staff, 6' Social Distancing)

RESTROOM FINDINGS

All restrooms measured during the initial ventilation assessment had more than adequate exhaust ventilation. However, there was one restroom visited, on the outside of the gymnasium which had an exhaust fan that did not appear to be working. It is possible that this has been addressed since our initial assessment. ASHRAE 62.1-2019 recommends 70cfm of exhaust per unit for public toilets when heavy periods of use are expected to occur. A unit is defined as a stall, or urinal.

Restroom Data:

Room	ACH	# of People per ASHRAE 70cfm/unit
Oracle Oak Bathroom	8.4	1
Salmon Creek Environmental Center Men's Restroom	7.0	2
Salmon Creek Environmental Center Women's Restroom	7.0	2
Madrone Bathroom	13.2	2

GYMNASIUM FINDINGS

While all classrooms that have economizers were equiped with MERV 11 filters, to maximze the quantity of outdoor air, the gymnasiun was outfitted with MERV 13 filters. The justification here is that this space is not currently being used by students, but could eventually be used as an indoor shelter-in-place area, as an alternative to an outdoor shelter-in-place location during wildfire season, and/or poor air quality. MERV 13 filters provide approximately 90% "equivalent outdoor air" for COVID-19, and remove ~85% of aerosol in the PM 2.5 size fraction.

The two large units provide a combined 8100cfm, given the large volume of the gym, this provides roughly 3 ACH even assuming 20% OA, and MERV 13 filters. Given the large volume of the gym, ACH is a less useful metric for assessing airflow. ASHRAE 62.1-2019 is a better guideline for assessing outside air. ASHRAE recommends 0.18cfm/ft^2 and an additional 20cfm of outside air per person. For a cohort of 25 students, and 1 instructor, the gym provides sufficent equivalent outdoor air to meet ASHRAE 62.1-2019 guidelines. Moreover, as a shelter-in-place facility, there is sufficient equivalent outdoor air for >300 people. If possible, in between classroom cohorts, allow for 3 air changes in-between, approximately 1 hour.

Gymnasium Data:

COVID-19 Mitigation Mode Analysis

Room	Combined ACH	cfm of OA Equivalent above ASHRAE Guidelines for 25 students
Gym	2.9	5682

Room	Number of People assuming 20cfm/person and 0.18cfm/sq ft
Gym	310

Wildfire and COVID-19 Mitigation Mode Analysis

Room	Combined ACH	cfm of OA Equivalent above ASHRAE Guidelines for 25 students
Gym	2.9	5520

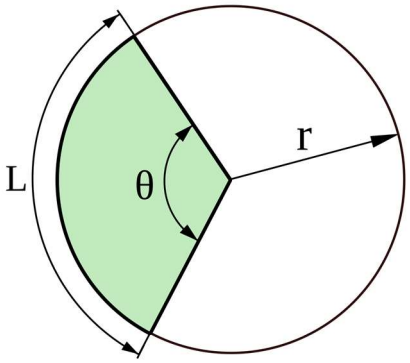
Room	Number of People assuming 20cfm/person and 0.18cfm/sq ft
Gym	302

CAFETERIA FINDINGS

Currently, while outdoor air quality has been good, students have been taking lunch outdoors. However, the cafeteria might be used in the future during lower air quality days. Therefore, it has also been equiped with MERV 13 filters in preparation for wildfire season.

Estimating room volume, using a modified formula for an area of a circle $A = \pi r^2 \frac{\theta}{2\pi} = \frac{r^2\theta}{2}$ with an assumed angle of 90˚. The inner wedge was subtracted from the larger wedge, to find the area of the Cafeteria.

$$Large\ Wedge\ \frac{r^2\theta}{2} - Smaller\ Wedge\ \frac{r^2\theta}{2} = \text{A of Cafeteria}$$



Circular Sector

Larger Wedge radius was ~56ft, and Smaller Wedge radius was 31ft. This resulted in an estimated 915sq ft, ~18ft^2 ceiling, and an estimated 16,472ft^3 room volume.

With these parameters, when the ventilation is in Fan On mode, the Cafeteria receives a staggering 19ACH from the HVAC alone. Furthermore, the 3 HEPA units provide an additonal ~1,500cfm of OA Equivalent. ASHRAE recommends 0.18cfm/ft^2 and an additional 7.5cfm of outside air per person. Given the high volume of air moving throught the Cafeteria when the HVAC is in Fan On mode, there are no ventilation related occupancy constraints for this space. Defer to Fire Marshall occupancy limits, and social distancing to estimate appropriate #s of occupants.

NURSE'S OFFICE FINDINGS

The corner office in Building B, which was discussed to be used as the Nurse's Office only recieves an estimated 1.7ACH. This value does not incorporate the benefit of a HEPA filter, that may have since been installed within the room. Approximately 200cfm of HEPA filtration would provide the recommended 6ACH for a nurse's office, even during wildfire season. This also does not account for the benefit of natural ventilation, as this calculation assumes windows and doors closed.

Nurse's Office Data:

COVID-19 Mitigation Mode Analysis

Room	Combined ACH	cfm of HEPA needed to achieve 6ACH
Nurse	1.7	187

Wildfire and COVID-19 Mitigation Mode Analysis

Room	Combined ACH	cfm of HEPA needed to achieve 6ACH
Nurse	1.5	192

MAIN OFFICE

Even without additional HEPA filtration, whether minimizing outdoor air, or maximizing outdoor air, the Main Office, and adjoining offices all receive more than the recommended minimum 3ACH for office spaces. In either scenario, there's more than sufficient OA Equivalent to accommodate multiple occupants maintaining social distancing.

Main Office Data:

COVID-19 Mitigation Mode Analysis

Room	Combined ACH	cfm of OA Equivalent above ASHRAE Guidelines for 1 Occupant
School Office	4.2	292
Cafeteria Office	5.4	94
Principal	4.5	111
Vice Principal	4.0	98

Wildfire and COVID-19 Mitigation Mode Analysis

Room	Combined ACH	cfm of OA Equivalent above ASHRAE Guidelines for 1 Occupant
School Office	3.9	268
Cafeteria Office	5.0	86
Principal	4.1	102
Vice Principal	3.7	90

DISCUSSION

This purpose of this assessment was to quantitatively evaluate airflow in all HUSD classrooms and office spaces with the HVAC, MERV, and HEPA filtration data specific to each classroom and office space. Our goal was to assess the impact of incorporating recommended changes proposed in our initial Februar 26th, 2021 ventilation assessment. Furthermore, to anticipate the potential impact of wildfire season, and the resiliency of system configurations. For example §3205. COVID-19 Prevention requires employers to "maximize the quantity of outside air provided to the extent feasible, except when the…(EPA) Air Quality Index is greater than 100 for any pollutant or if opening windows or letting in outdoor air by other means would cause a hazard to employees, for instance from excessive heat or cold."

The increased MERV filtration, and the IQ*Air* CleanZone SL theoretically provides sufficient "Equivalent Outdoor Air" for COVID-19 mitigation when economizers, doors, and windows are closed to prevent air pollution from wildfire smoke entering the classrooms. However, during the next extreme wildfire smoke event, it is recommended that real-time exposure monitoring be peformed to confirm PM 2.5 is well controlled by MERV and HEPA filtration. MERV 11 was chosen for those spaces with economizers, to maximize the amount of outside air coming into the classroom. However, if Harmony opts to upgrade from MERV 11 to 13 for all spaces, it is recommended to ensure airflow is still sufficient. It is worth noting that CO_2 levels would rise to undesirable levels with outside air being minimized. Therefore, real-time exposure monitoring, and/or a follow-up study is recommended to determine that optimal in-between point with CO_2 and PM 2.5.

All classroom, and office economizers were programed to open when the fan is in operation. Our calculations assumed a conservative 20% OA, but the OA is likely closer to 30%. HUSD set an internal benchmark of 6 ACH for each classroom, and exceeded this in all cases. However, this would not have been possible without the introduction of MERV filtration, reinforcing the importance of a regular filter changeout schedule.

ASHRAE recommends a daily flush of the ventilation prior to occupancy: "Mechanical Systems should be operated in occupied mode (including normal or peak outside air rate introduced to each space) for minimum period of 2 hours prior to occupants re-entering building." However, ASHRAE also states that the primary goal is to achieve 3 air changes.

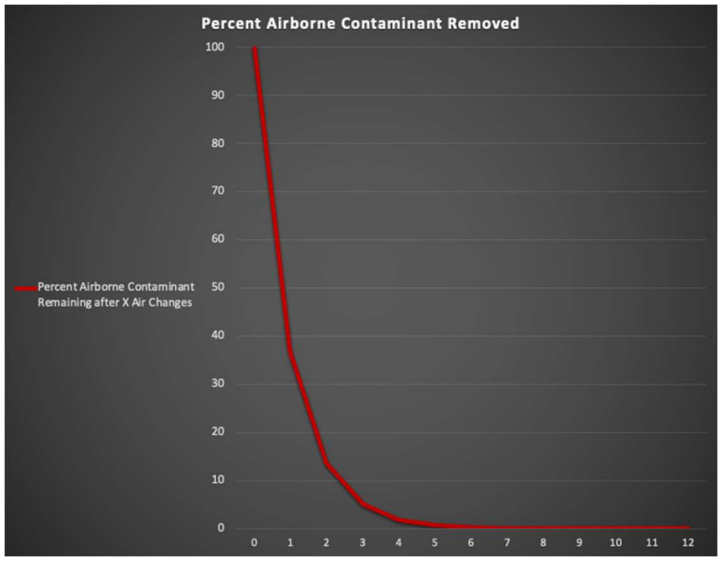
> The building is flushed for a duration sufficient to reduce concentration of airborne infectious particles by 95%. For a well-mixed space, this would require three air changes of building volume based on outside air cfm (or three equivalent air changes including the effect of filtration and air cleaners) (ASHRAE Aug 2020)

Therefore, running HVAC and HEPAs 30 minutes prior to occupancy, and 30 minutes after, provides sufficient air changes to meet this recommended 3 air changes.

While there isn't an agreed upon consensus regarding the appropriate number of air changes for schools, Harvard's Schools for Health, has advocated for between 4-6 air exchanges per hour (ACH). However, worth noting, is that because ACH is an exponential decay function, the law of diminishing returns applies. The biggest reduction in airborne contaminants in a well-mixed room, as seen in the ACH Table, and ACH Graph below, occurs from 0 to 1 ACH, and progressively diminishes as the number of air changes goes up. The difference between 0-1 is ~63%, whereas the difference between 4-5 is 1.1%. Therefore, the most significant gains in COVID mitigation will likely come from ensuring we address those spaces with severely deficient airflow, as opposed to increasing a space from 4 to 6 ACH.

Air Changes	Percent Airborne Contaminant Remaining after X Air Changes
0	100
1	37
2	14
3	5.0
4	1.8
5	0.7
6	0.2
7	0.09
8	0.03
9	0.01
10	0.005
11	0.002
12	0.001

ACH Table



ACH Graph

RECOMMENDATIONS

- Develop a contingency plan for Harmony for wildfire smoke events
  - Determine who will be responsible for monitoring the AQI
  - Consider installing local PM monitors, such as PurpleAir, or Clarity
  - Revisit school closure criteria
  - Consider exposure monitoring during the next wildfire event to determine effectiveness of MERV and HEPA filters
  - Ensure compliance with §5141.1 Protection from Wildfire Smoke
    - In particular, determine who will be exposed to an AQI of >151 for more than 1 hour
    - Anyone working indoors, with Harmony's ventilation, should be well protected
- Continue to ensure MERV and HEPA filters are replaced as needed
- Remeasure airflow when filters are changed to determine if airflow is changed
- Consider remeasuring airflow when economizers are closed to ensure sufficient air exchanges
- Track allergens, and consider reducing outside air, if students and staff are impacted by allergens

CONCLUSION

Respiratory aerosol can remain airborne for hours in stagnant indoor environments, if it is not removed through dilution or filtration ventilation. There is no one control measure that will take our risk of COVID-19 to zero. However, the combination of increasing outside air, installing the highest compatible MERV filtration, ongoing maintenance, the use of HEPA filters, and encouraging the use of natural sources of dilution ventilation, should provide well in excess of the recommended levels of ventilation for schools. It is essential that HEPA filters be properly

maintained, and monitored for when their filters need to be replaced. Prefilters can extend the useful life of a HEPA filter. Intrinsic will put together a cost estimate for this continued work to occur over the summer.

While no specific number of air changes per hour has been established as a standard to be met for mitigating COVID, we do know that <1 ACH is typical of a home environment (EPA). Transmission rates in homes with close contacts has been estimated to be 10 times higher than other contacts. ASHRAE reminds us that 95% of any airborne contaminant in a "well-mixed" space are removed after 3 air changes. Based upon our assessment and analysis, HUSD has met or exceeded CDPH, CDC, and Sonoma County guidance for safely reopening Harmony Union School District.

Given how dynamic and unpredictible the pandemic is, it's imperative for us to stay in tune with local, County, and State guidance.

We hope that you find this report helpful in understanding the value of the ventilation upgrades Harmony Union School District made. These improvements to the ventilation ensures the risk for both COVID-19 and wildfire smoke are mitigated to the greatest extent feasible, protecting Harmony Union School District students, teachers, staff, and community.

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