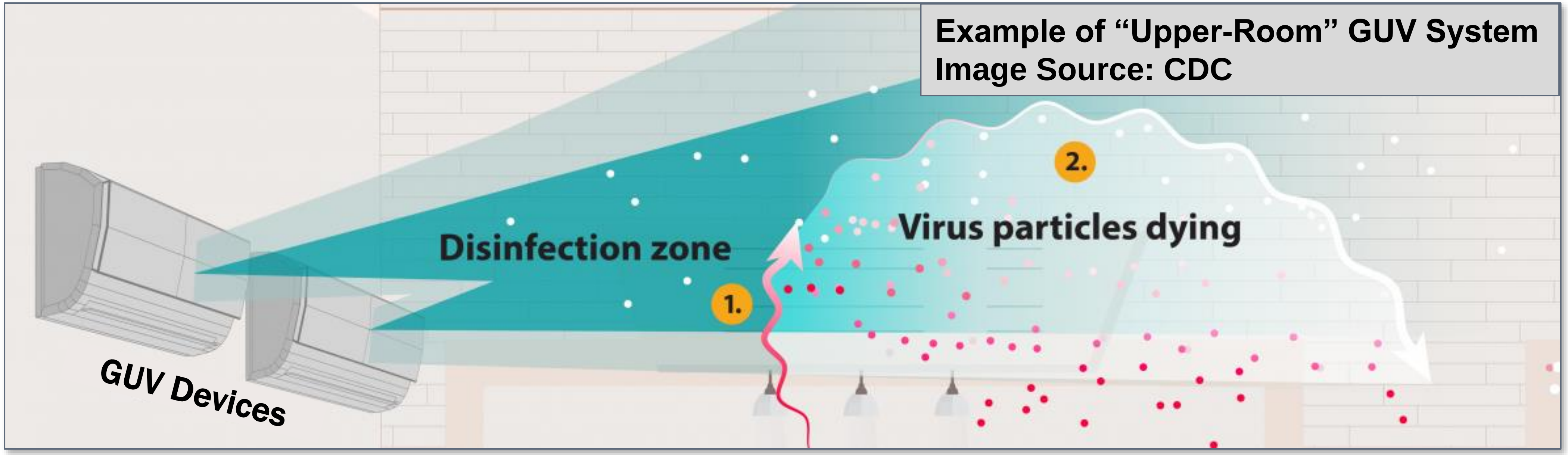
Germicidal Ultraviolet (GUV) Disinfection for Energy Savings, Decarbonization, and Healthier Buildings



Example of "Upper-Room" GUV System
Image Source: CDC

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WBS # 3.2.1.06

Project Summary

Objectives

- Identify the most effective and energy efficient methods to reduce airborne disease transmission in buildings
- Characterize GUV energy efficiency, decarbonization, and electrification benefits
- Address GUV technical barriers needed to scale technology for safe and effective deployment

Left: “Upper-room” GUV installation at Cambridge Friends School, Cambridge, MA
Right: “Whole-room” GUV installation at Hartsfield-Jackson Atlanta Airport

Stats

Performance Period: FY23 (Ongoing FY22-24 project)

DOE budget FY23 (new BA): $1,040k, **Cost Share:** $0k

FY23 Milestone 1: Complete one public report of GUV product testing

FY23 Milestone 2: Host sites selected for field evaluations

FY23 Milestone 3: Experimental design complete for simulation studies

FY23 Milestone 4: Draft standardized framework complete

FY23 Milestone 5: First report of field evaluation results complete

FY23 Milestone 6: Report of simulation study results complete

FY23 Milestone 7: Complete two additional product testing reports

Team and Partners

Pacific Northwest National Laboratory:
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Lawrence Berkeley National Laboratory:
Brett Singer, Woody Delp, Michael Sohn, Jacob Bueno de Mesquita

External Research Partners:
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Ernest Blatchley, Ph.D. – Purdue University

Team

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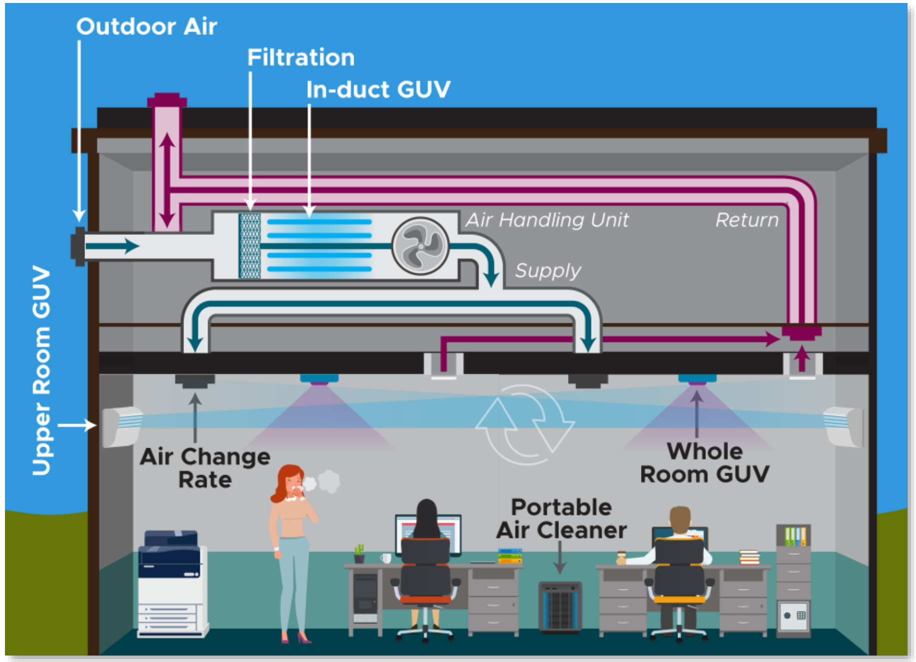
UV Photochemical Processes

Problem

- Absenteeism costs U.S. businesses over $200B annually, reduces student learning, and exacerbates public health and education inequities
- Infections from airborne diseases that drive absenteeism (COVID-19, RSV, influenza, etc.) primarily occur inside buildings
- A new ASHRAE design standard to reduce airborne disease transmission in buildings is on the way
  - How can we meet the standard in the most energy efficient way?

Measures to reduce airborne disease transmission in buildings



- Using increased ventilation to reduce transmission **has limited effectiveness** and **results in large potential increases to building energy use and carbon emissions.**
- Current evidence indicates **germicidal ultraviolet (GUV) systems are more effective and may use up to 90% less energy than ventilation**, but further characterization and validation is needed.

Alignment and Impact

THIS GUV PROJECT ALIGNS WITH AND ADDRESSES MULTIPLE EERE/BTO GOALS

Energy Efficiency

- Use GUV as more efficient alternative to increasing ventilation above code or disabling demand-controlled ventilation
- Improve GUV technology and application efficiency

Decarbonization

- Reduce carbon emissions associated with fossil fuel heating needed for ventilation by using electric GUV alternative

Electrification

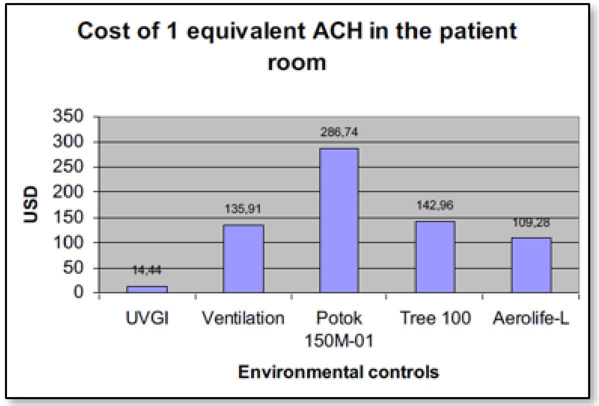
- Supports heating system electrification by reducing ventilation load, thereby reducing size, cost, infrastructure requirements needed for electric heat pumps to replace fossil fuel heat

Equity and Affordability

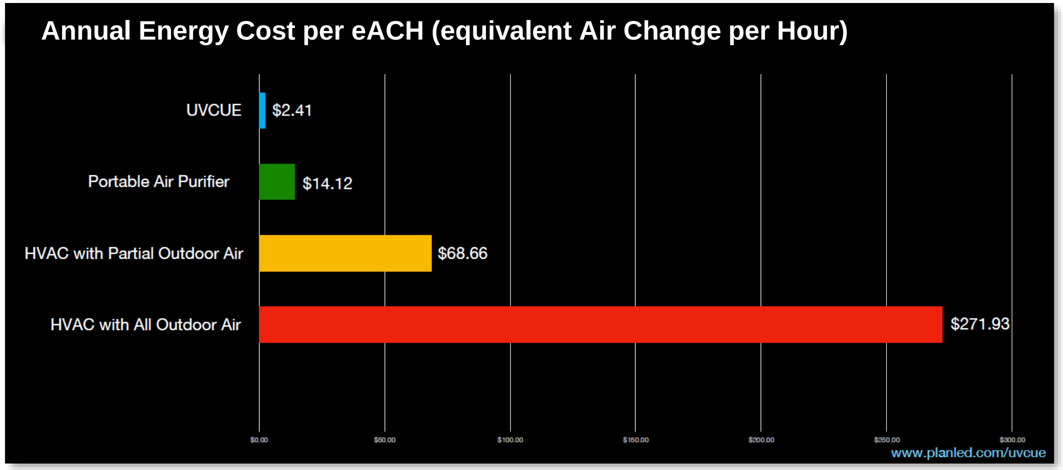
- Use GUV as more economical and efficient solution for buildings without sufficient HVAC – as often found in disadvantaged communities
- Reduce public health and education inequities resulting from airborne infections

Alignment and Impact

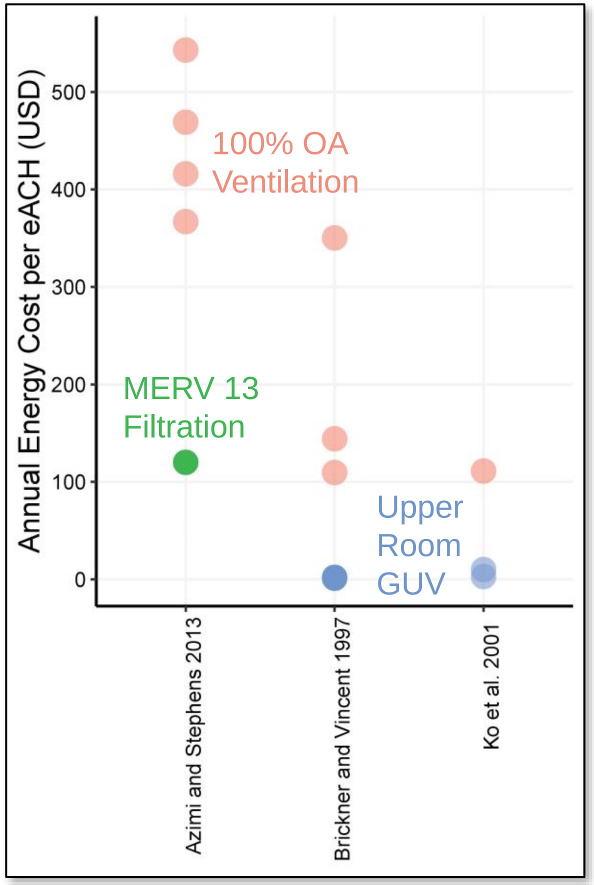
ENERGY EFFICIENCY AND DECARBONIZATION IMPACT: Previous research and vendor studies indicate large potential energy and carbon savings vs. ventilation for equivalent disinfection but needs the more sophisticated analysis and objective validation provided by this DOE-funded effort.



CDC unpublished research study of various mitigation measures finds 98% lower operating cost of GUV vs. equivalent ventilation in patient room (Jensen and Volchenkov)



Manufacturer study of various mitigation measures finds 96%+ lower energy cost of GUV vs. ventilation (PlanLED)



PNNL 2022 literature review of peer-reviewed research finds GUV uses much lower energy cost per eACH in the studied conditions (Abboushi et al.)

Approach

KEY GUV TECHNOLOGY BARRIERS

Benefits and Value Proposition

- GUV effectiveness, economic, energy, carbon benefits relative to alternatives is not sufficiently characterized and quantified, resulting in incomplete value proposition
- Many current studies are not comparable

Product Performance Testing/Reporting

- Product performance data needed for safe and effective deployment is often inaccurate and/or incomplete
- Standards and capabilities to test and report GUV product performance are still emerging

Awareness/Education

- Stakeholders are generally unaware of and uneducated about GUV opportunity
- Uncertainty: Does it work? How well does it work? Is it safe?

Application Standards/Guidelines/Tools

- Guidelines and tools for how to safely and effectively apply the technology are still emerging
- Ventilation codes/standards do not yet include GUV or health-based targets – currently under development by ASHRAE

Approach

PROJECT TASKS TO ADDRESS BARRIERS

Simulation Model

- Characterize and quantify effectiveness, energy efficiency, decarbonization, electrification benefits across building types and climate zones

Product Testing

- Independently test commercially available GUV products; assess current test methods
- Educate to reduce inaccurate and/or incomplete product claims

Framework Development

- Propose a framework including metrics and key considerations to improve comparability of measures across research studies
- Define standard reference scenarios

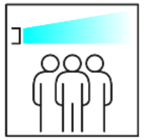
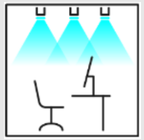
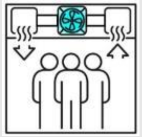
Field Evaluations

- Assess and demonstrate real-world applications for effectiveness, energy, safety, and more
- 2 new installs and 10 existing installs

Approach – Product Testing Program

- Test commercially available "off-the-shelf" GUV products
- Assess new and emerging test standards/methods
- Assess accuracy of manufacturer claims
- Compare performance of different technologies and product designs; identify efficiency opportunities
- Publish findings and use to improve standards; educate product developers, specifiers, and buyers

GUV Product Types

	Type	Description
	Tower	A portable GUV device placed on horizontal surfaces such as floors or tables to disinfect air and surfaces; these products are generally intended for use when the room is unoccupied.
	Upper-room luminaire	A GUV device mounted to upper walls or ceilings to disinfect air in the portion of the room above occupants; this allows for safe use of the room when the device is operating, but requires sufficient air mixing between upper and lower portions of the room.
	Whole-room luminaire for vacant rooms	A GUV device mounted to ceilings to disinfect air and surfaces throughout the room; UV exposure is generally above safety limits, so safeguards are needed to prevent operation when the room is occupied.
	Whole-room luminaire for occupied rooms	A GUV device mounted to ceilings to disinfect air and surfaces throughout the room without exceeding safety limits, allowing for use in occupied rooms.
	In-duct unit	A GUV device installed in HVAC equipment, typically within or near the exit of an HVAC air-handling unit to disinfect air before it is supplied to a room; UV is contained inside the equipment, allowing for use in occupied rooms.
	Room air cleaner	A GUV device that uses a fan to draw air into a chamber and then exhausts disinfected air into a room; UV is contained inside the chamber, allowing for use in occupied rooms.

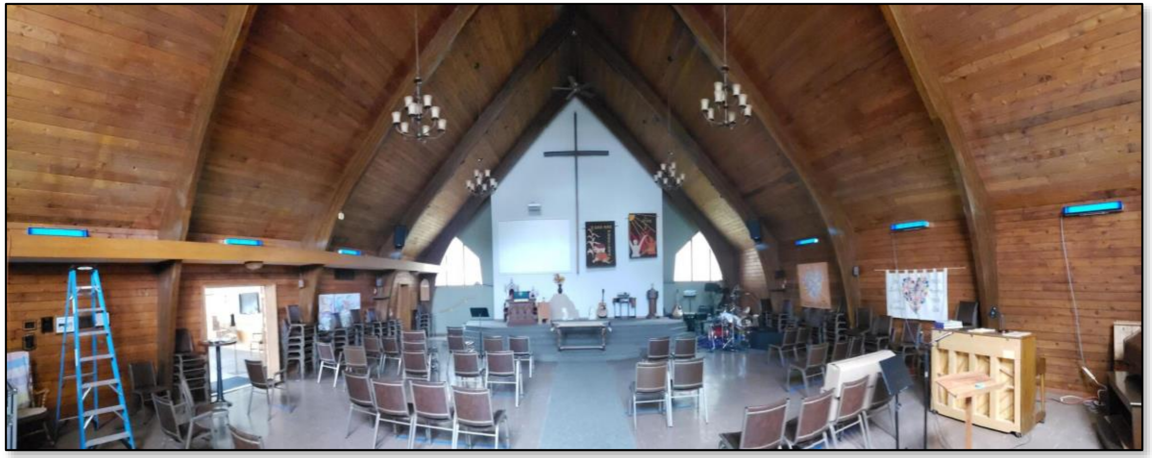
Approach – Field Evaluations

How does GUV perform in the real world?

- 2 New Installations
- 10 Existing Installations

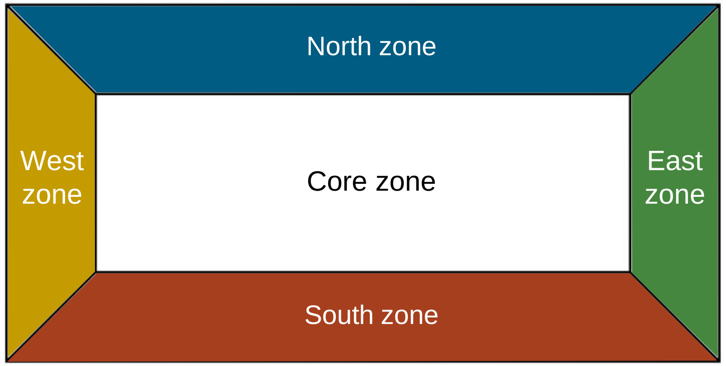
Research Questions and Scope:

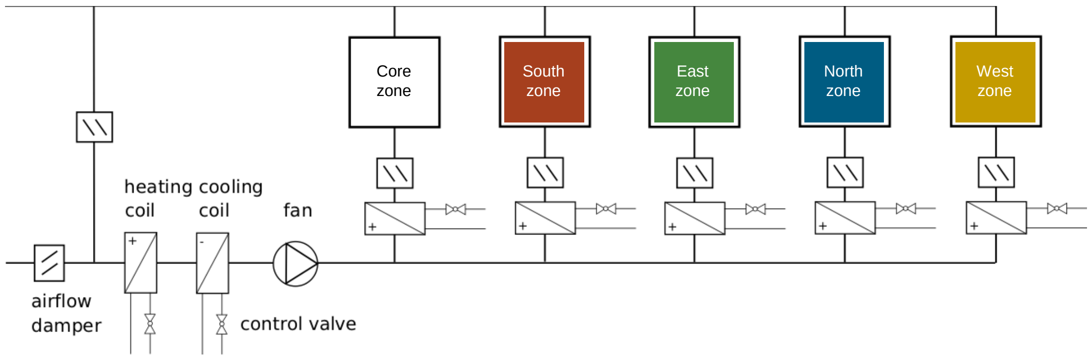
- Are GUV installations safe and effective?
- How are GUV systems operated and maintained for ongoing safety and effectiveness?
- How much energy does GUV use in real-world applications?
- What has been the occupant experience with the technology?



Approach – Simulation Model

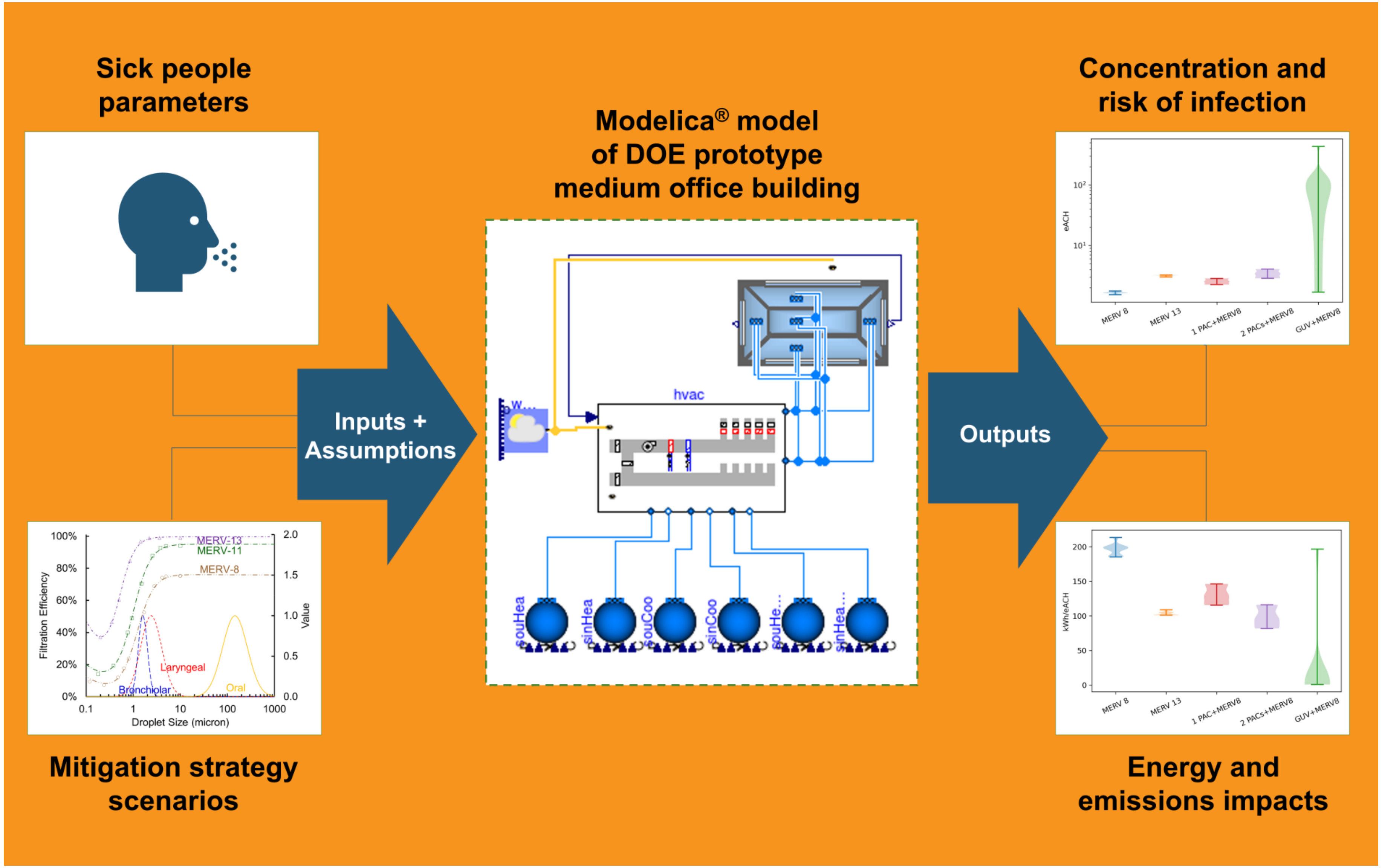
Determine most effective and energy efficient approaches to reduce transmission





- Use Modelica model representing a single floor of the DOE Prototype Medium Office Building
- Simulate various combinations of pathogen mitigation measures across different climate zones
- Compare ventilation, filtration, upper room GUV, whole-room GUV, in-duct GUV, portable air cleaners
- **Assess efficacy, energy use, and carbon emissions**
- **Characterize most effective and energy efficient approaches**

Approach – Simulation Model



Approach – Framework Development

Propose a standard framework to improve comparability of germicidal efficacy and energy use across research studies

Example questions to be investigated:

- What energy use metrics should be recommended? Is a normalization needed?
- What data and assumptions should be reported?
- What considerations should be addressed when making comparisons (transmission routes, application scales, etc.)?

Level 1

Laboratory, field, and simulation studies

A framework for addressing metrics and key considerations when comparing the germicidal efficacy and energy use in research studies to improve comparability

Level 2

Simulation studies

Clearly defined priority reference spaces and buildings, along with disease transmission scenarios, to promote consistent comparisons across simulation studies

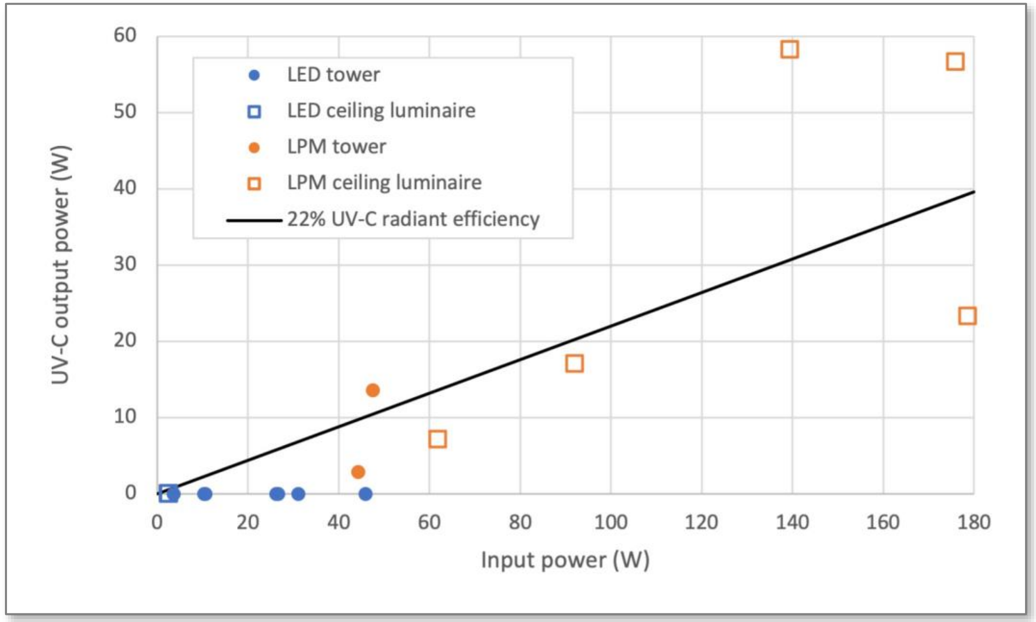
Detailed definition of spaces and buildings as well as disease transmission scenarios to serve as standardized test beds.

This can pave the way for a reference database and development of tools to help facility managers and other decision makers choose the most effective and efficient options for their application.

Progress and Future Work – Product Testing Program

Progress to Date:

- Completed Round 1 of product testing of consumer towers and whole-room GUV products
- Final reports in DOE approval processes, hopefully published soon



By the end of FY23:

- Complete 1–2 additional rounds of testing focusing on upper-room and whole-room GUV products

Planned/scoped for FY24, but not yet funded:

- Complete additional test rounds focusing on other product types or performance aspects
- Complete round-robin testing across different test labs to compare results
- Work with industry to address identified shortcomings

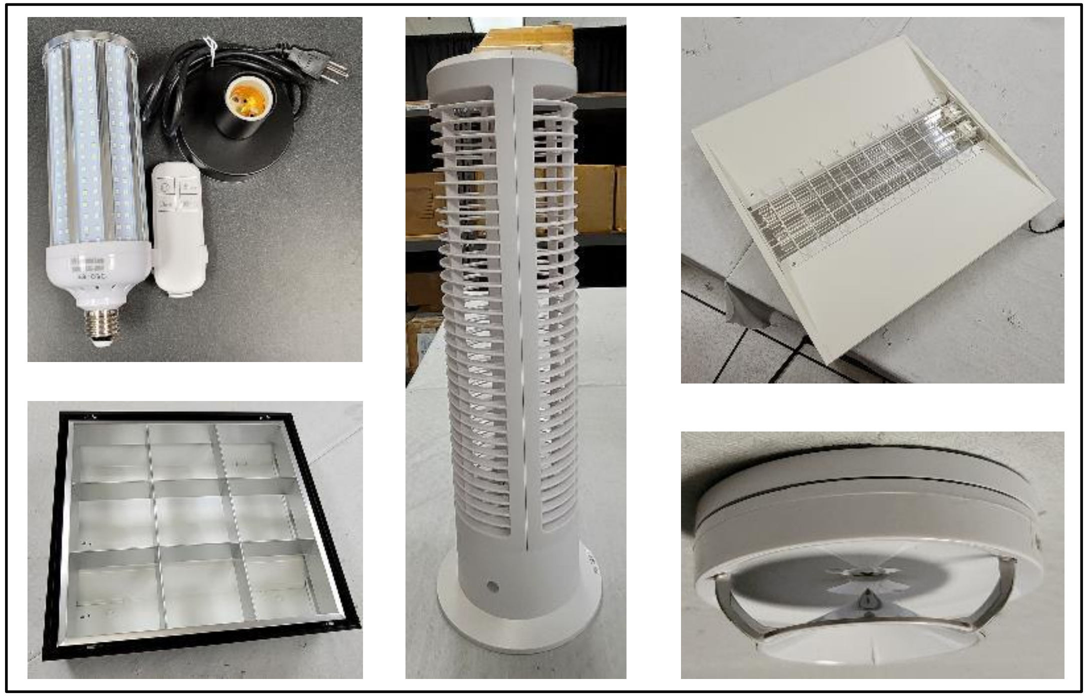
Potential future work not yet scoped or funded:

- More rounds, education, test standards/ capability development until issues are addressed

Progress and Future Work – Product Testing Program

Round 1 Results

- 7 consumer-oriented LED and low-pressure mercury (LPM) towers
- 6 whole-room LPM and LED luminaires



Key Findings

- Some consumer towers do not produce UV-C as claimed
- Inaccurate claims and/or units were found across all product types
- Wide variation in efficiency, even among same technology/product type
- Rapid depreciation of some UV-C LED products
- Test lab issues:
  – Capability gap to accurately test larger dimension GUV products
  – Differences in results between measurement equipment (gonio vs. sphere)

Progress and Future Work – Field Evaluations

Progress to Date:
- Site recruitment complete, 36 received, 12 selected to move forward, now obtaining formal commitments
- Field measurement/assessment protocol under development


Credit: Bill Palmer

By the end of FY23:
- Complete evaluations of at least 5 sites

Planned/scoped for FY24, but not yet funded:
- Complete evaluations of remaining sites and publish findings

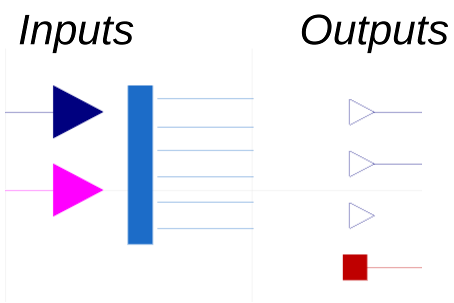
Potential future work not yet scoped or funded:
- Conduct longitudinal studies on safety using wearable UVC data loggers
- Support UV workforce programs with case studies and other educational materials
- Conduct evaluations of different GUV products, technologies, or application designs

Progress and Future Work – Simulation Model

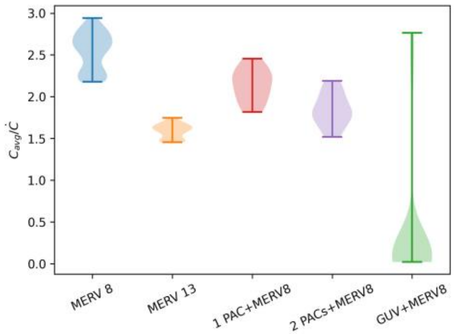
Progress to Date:

- Scope and experimental design complete
- Medium-office building model created
- Simulations and sensitivity analysis underway

$$\dot{C}_{GUV} = f_{rad} k_{rad} E_{avg} V C$$



UR-GUV component model



Preliminary results

By the end of FY23:

- Report generalized findings that quantify effectiveness, energy use, GHG emissions of various disease transmission mitigation strategies including GUV

Planned/scoped for FY24, but not yet funded:

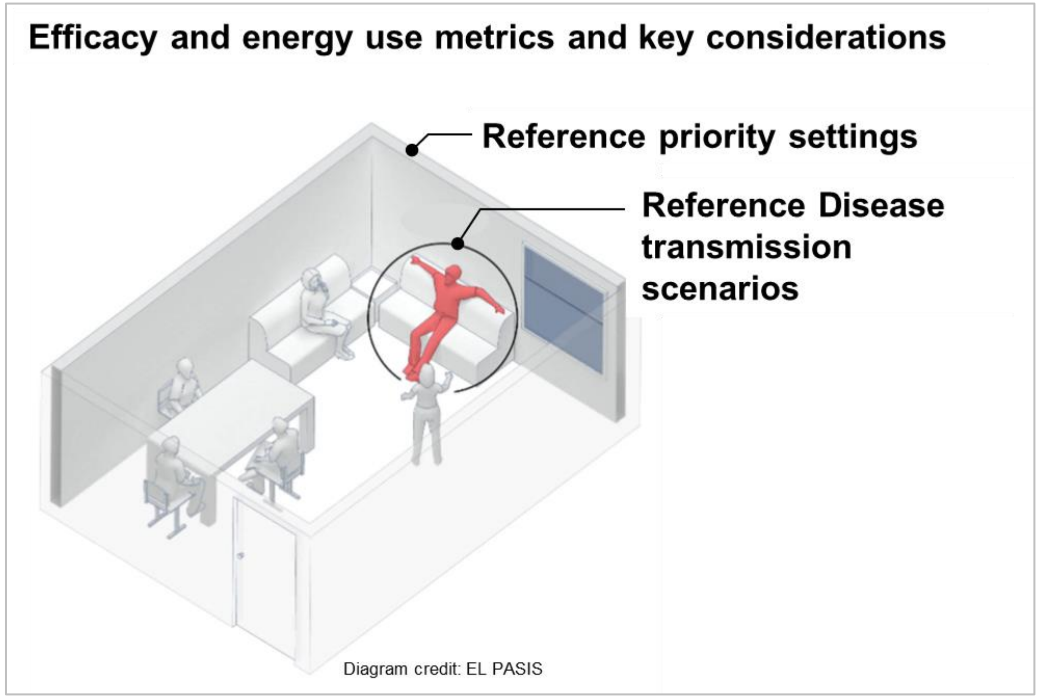
- Apply framework to additional field evaluation studies and future simulation work
- Promote framework to larger research community

Potential future work not yet scoped or funded:

- Expand model to school, restaurant, hotel, grocery, other high value applications
- Incorporate cost data to optimize for overall cost-effectiveness of measures
- Develop educational resources and tools for stakeholders to apply findings

Progress and Future Work – Framework Development

Progress to Date:
- Literature review complete
- Priority spaces and reference disease transmission scenarios identified
- Currently vetting proposal with experts



By the end of FY23:
- Framework proposed via journal article, whitepaper, or DOE report
- Apply framework to FY23 field evaluation and simulation projects

Planned/scoped for FY24, but not yet funded:
- Apply framework to additional field evaluation studies and future simulation work
- Promote framework to larger research community

Potential future work not yet scoped or funded:
- Develop or support reference database of studies that comply with framework

Thank You

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REFERENCE SLIDES

Project Execution

	FY2022				FY2023				FY2024			
Planned budget												
Spent budget												
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Past Work												
Q2 Milestone: Initial report on GUV energy implications												
Go/No-Go: Initial GUV deliverables demonstrate impact												
Current/Future Work												
Q2 Milestone: Round 1 product testing report (test lab delays)												
Q2 Milestone: Field evaluation sites selected												
Q2 Milestone: Simulation model experimental design complete												
Q3 Milestone: Draft standardized framework complete												
Q4 Milestone: 5+ Field sites evaluated and analyzed												
Q4 Milestone: Simulations and associated draft report completed												

EERE/BTO goals

The nation's ambitious climate mitigation goals

Greenhouse gas emissions reductions

50-52% reduction by 2030 vs. 2005 levels

Net-zero emissions economy by 2050

Power system decarbonization

100% carbon pollution-free electricity by 2035

Energy justice

40% of benefits from federal climate and clean energy investments flow to disadvantaged communities

EERE/BTO's vision for a net-zero U.S. building sector by 2050