SMART VENTILATION

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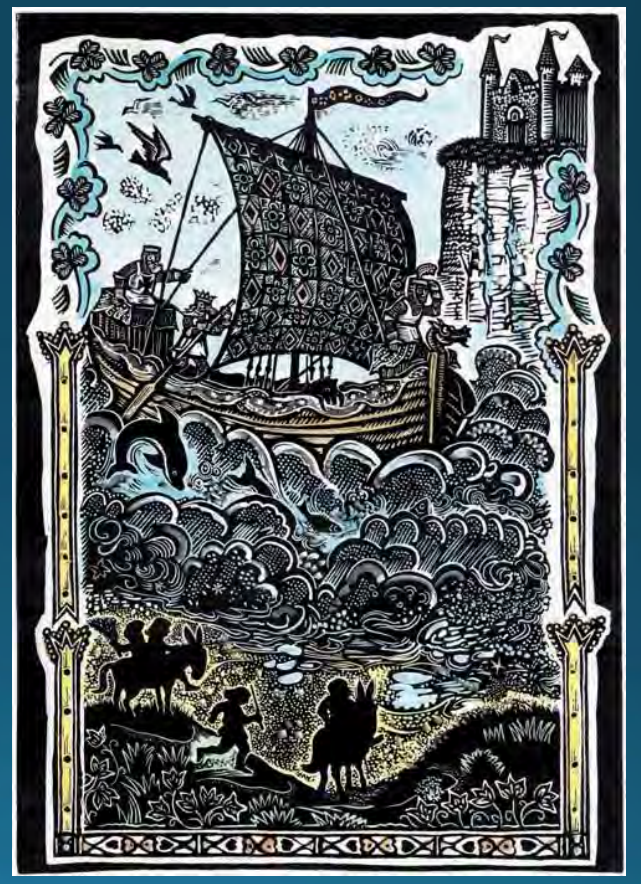
WHAT IS VENTILATION

- Medicine: To Exchange Air In the Lungs
- Latin: *Ventilare*, “to expose to the wind”
- Today: To Bring In Outdoor Air And Replace Indoor Air Of The Occupied Space
- Is that the same as IAQ?

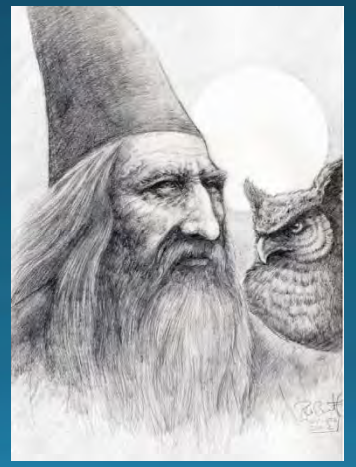


WHY DO WE VENTILATE?

- Health
- Odor
- Energy
- Moisture
- Durability
- Safety
- Sustainability
- Thermal Comfort

WHY DID WE VENTILATE?

- Learn from early man
- Learn from history
- Learn from science



NEOLITHIC TIMES

- Fires In Caves Had To Be Ventilated Since Man domesticated fire…200,000 yrs ago
- First Homes 10,000 years ago, but they had open roofs to exhaust contaminants.
- Banpo Villagers of China Had Chimneys 7000 years ago
- Early people knew how to ventilate for safety
  - They learned the hard way

MINOAN KNOSSOS NATURALLY VENTILATED

- 4000 yr ago in Crete
  - Architects of Atlantis
- Palace of King Minos
  - Natural Ventilation
  - Labyrinth was?
  - Minotaur was?
  - Daedalus was?
- Where did the King Live?

SLIGHTLY MORE MODERN TIMES

- Combustion was still key contaminant
- Roman Houses & Large Buildings Had Designed Ventilation System
- Examples from Traditional Societies in temperate and cold climates
  - Basketweaver Pits at Mesa Verde 750A.D
- Designed natural ventilation
  - Combustion outside living space

EARLY HEALTH CONCERNS

- More Than Combustion
- Egyptians Noted Health of Pyramid Stonecutters Improved With Ventilation
- 1st Ventilation Standard: 1631 King Charles of England Decreed That There Must Be Ventilation
  - Ceiling at least 10 feet high
  - Windows taller than they are wide
  - For health and safety

ENGLISH HISTORY

- London Fire of 1666 Improves Buildings
  - Reversed By 18th Century Window Tax
- Parliament had first sick building syndrome

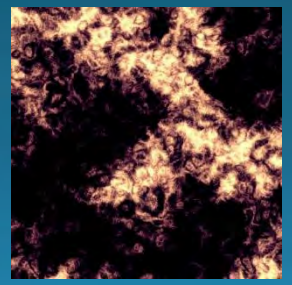
  It was *foul, rancid and pestiferous*
  - Mechanical ventilation Added in 1734 (Wren designed)
  - Burned down a century later
  - New design study commissioned
- First ventilation science for British MPs
  - Tredgold, 1834: 4 cfm/p (2 l/s/p)
    - First ventilation rate

Ventilation paradigms and rates have changed many times

What About Now?

LATE 20th CENTURY

- Oil shock focusses attention on energy
  - Push for tighter envelopes
  - Push for lower ventilation
- International Energy Agency was created
- New products appear indoors
- Unintended consequences on IAQ
- Need to know why we ventilate now



WE VENTILATE FOR COMFORT

- Thermal Comfort (IEQ not IAQ)
  - Prevents overheating by venting excess heat
  - Air movement makes us feel cooler
  - Economizers in dry climates
- Odor Control
  - Ventilation justification of 20th century
  - Occupants are best “sensors” –can take actions

Key Odor: US!

- People Emit “Human Bioeffluents”
  - CO_2 is only surrogate
- Daily Hygiene of Western World
  - 2.5 L/s adapted (occupants)
  - 7.5 L/s unadapted (visitors)
- Dominates In High-Density Spaces
- Sets Floor Otherwise

WE VENTILATE FOR HEALTH

- Occupants not usually good sensors
  - So, we must design healthy buildings
- Key Questions:
  - What are the important contaminants?
  - How do we measure harm from them?
  - How do we mitigate that harm?
- CO_2 (& contagion) not typically a justification
  - Productivity/ventilation link needs more work
- Ventilation justification of 21st century

Ventilation can have negative consequences (or not)

CAN WE BE SMART?

Ventilating SMART

- Change WHEN and at what RATE you ventilate to:
  - Reduce energy use
  - Maintain or improve IAQ

- Energy reductions. Operate ventilation system LESS when:
  - Temperature and humidity differences are biggest
  - Other fans (kitchen, bath, clothes dryer, economizer) are operating
  - Home not occupied
  - In-response to demand response or pricing signals from utilities

- Maintain IAQ: Real-time control or scheduled ventilation
  - EQUIVALENCY.
    - Have same or better exposure as a continuously operating fan for a constantly emitted pollutant
  - Install an over-sized fan
  - Limit peak concentrations when system off.
  - Reduce ventilation when outdoor air is poor: high particles or ozone

ASHRAE Standard 62.2

- U.S. Standard for dwelling ventilation; regulation by local areas
- Uses concept of Equivalence
  - i.e. effect is same if dose of generic contaminant is the same
- Considers variable ventilation
  - Effect of exogenous ventilation (e.g. local exhaust)
  - Allows for infiltration (but not natural ventilation)
- Considers occupancy, but not solely
- First *Smart* Ventilation Standard
- So we will use it to exemplify smart ventilation approach

What does “Equivalence” mean?

- Have a time-varying ventilation rate that gives the same exposure as a continuous ventilation rate
- Assumes a constant indoor emission rate of pollutant
- Uses time series of actual ventilation (Q_i) to calculate the time series of relative exposure.
- Example:

Target ventilation is Q_{tot} from Equation 4.1 in ASHRAE 62.2:

$$Q_{tot}\ (cfm) = 0.03A_{floor} + 7.5(Nbr + 1) \qquad \text{(I-P) (4.1a)}$$

$$Q_{tot}\ (L/s) = 0.15A_{floor} + 3.5(Nbr + 1) \qquad \text{(SI) (4.1b)}$$

Real-Time Control: Calculations of Relative Exposure

For each time step, i, of length Δt calculate Relative exposure, Ri:

Non-zero Q_i

$$R_i = \frac{Q_{tot}}{Q_i} + \left(R_{i-1} - \frac{Q_{tot}}{Q_i}\right) e^{-Q_i \Delta t / V_{space}}$$

Zero Q_i:

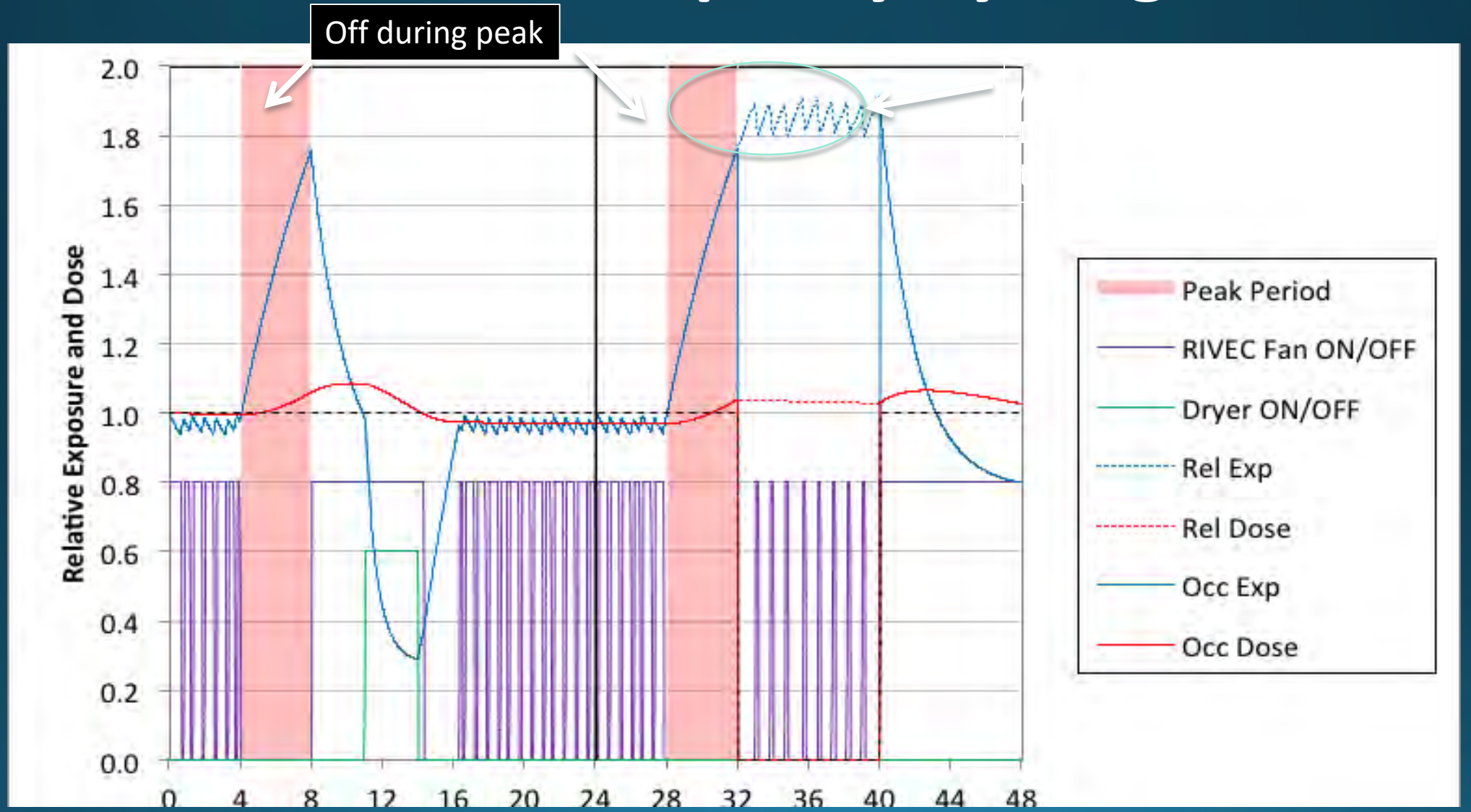
$$R_i = R_{i-1} + \frac{Q_{tot} \Delta t}{V_{space}}$$

Ri is averaged over the year. The average MUST be less than one *during occupied periods*.

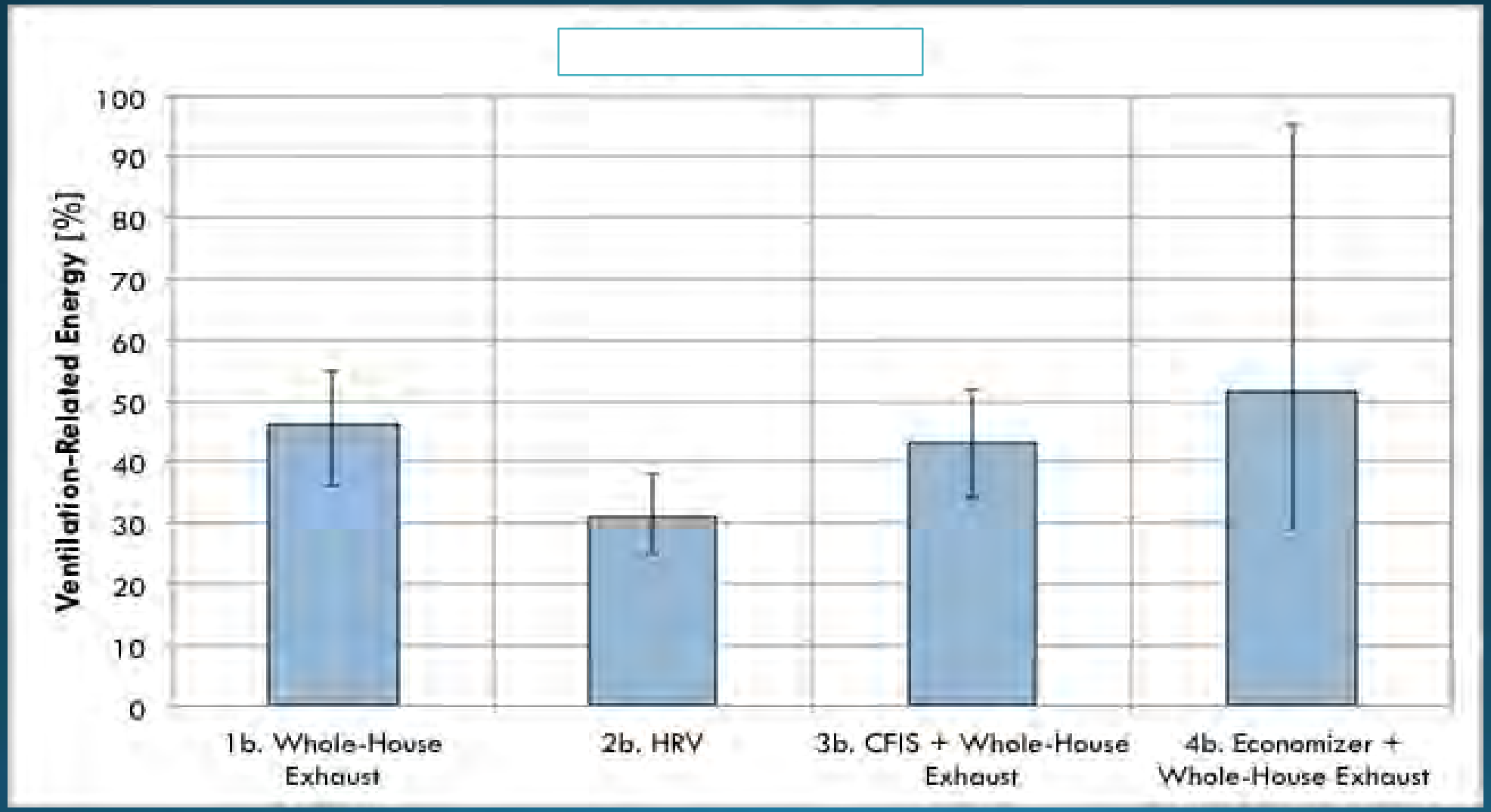
RIVEC Example

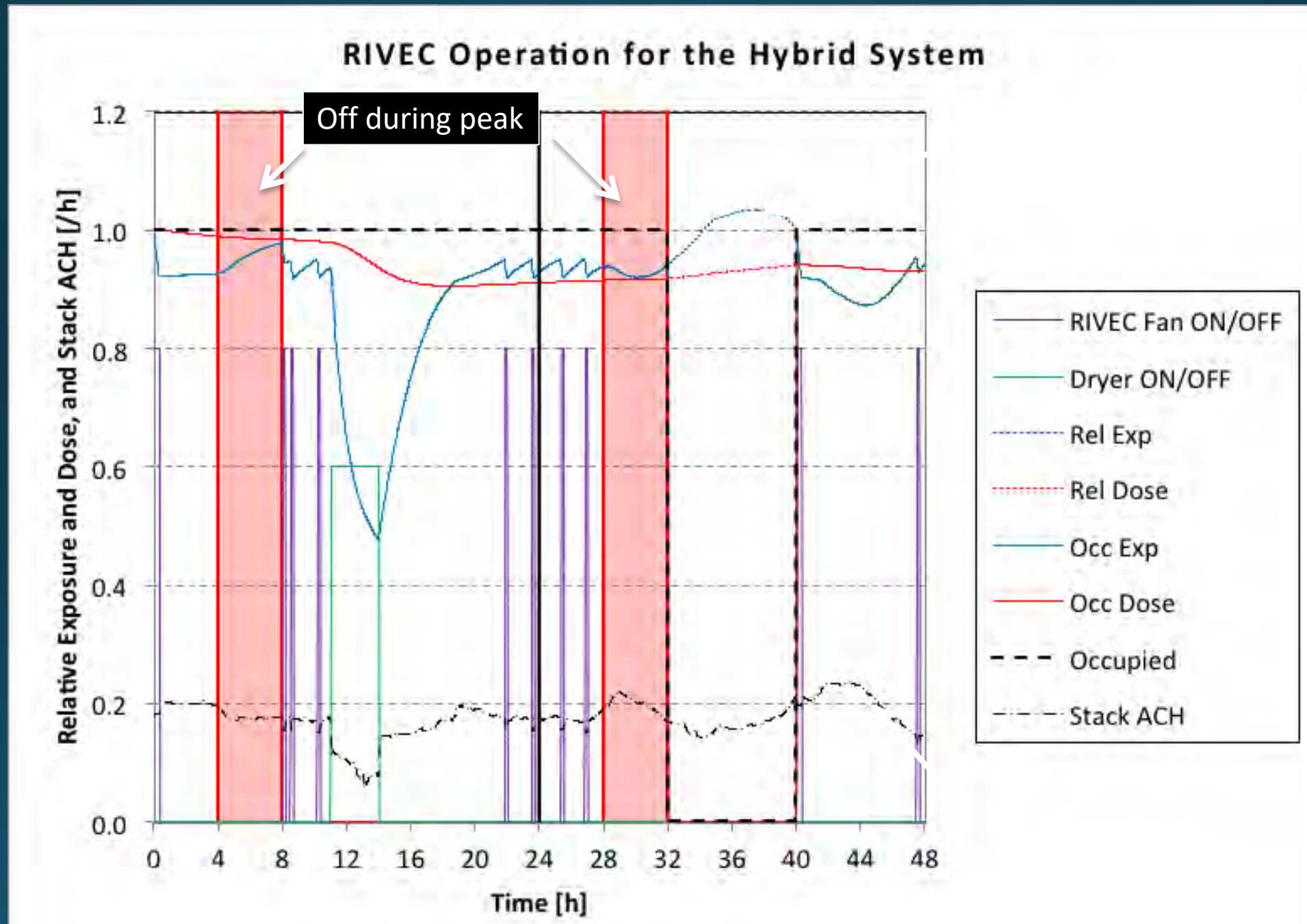
- Turn off a ventilation system for four hours a day to avoid peak temperature difference
- Ventilate less when the house is unoccupied
- Use an oversized fan to ventilate more at other times to achieve a Relative Exposure less than one
- No infiltration credit taken – although this is outlined in ASHRAE 62.2
- Use a controller to turn fan on if Relative Exposure > 1 (or > 2.5 during unoccupied times)
  - Also keep Relative “dose” (a 24 hour running average) below 1
  - Make fan on/off decision every 15 minutes

RIVEC & Occupancy Cycling



Savings by Ventilation System (CA)

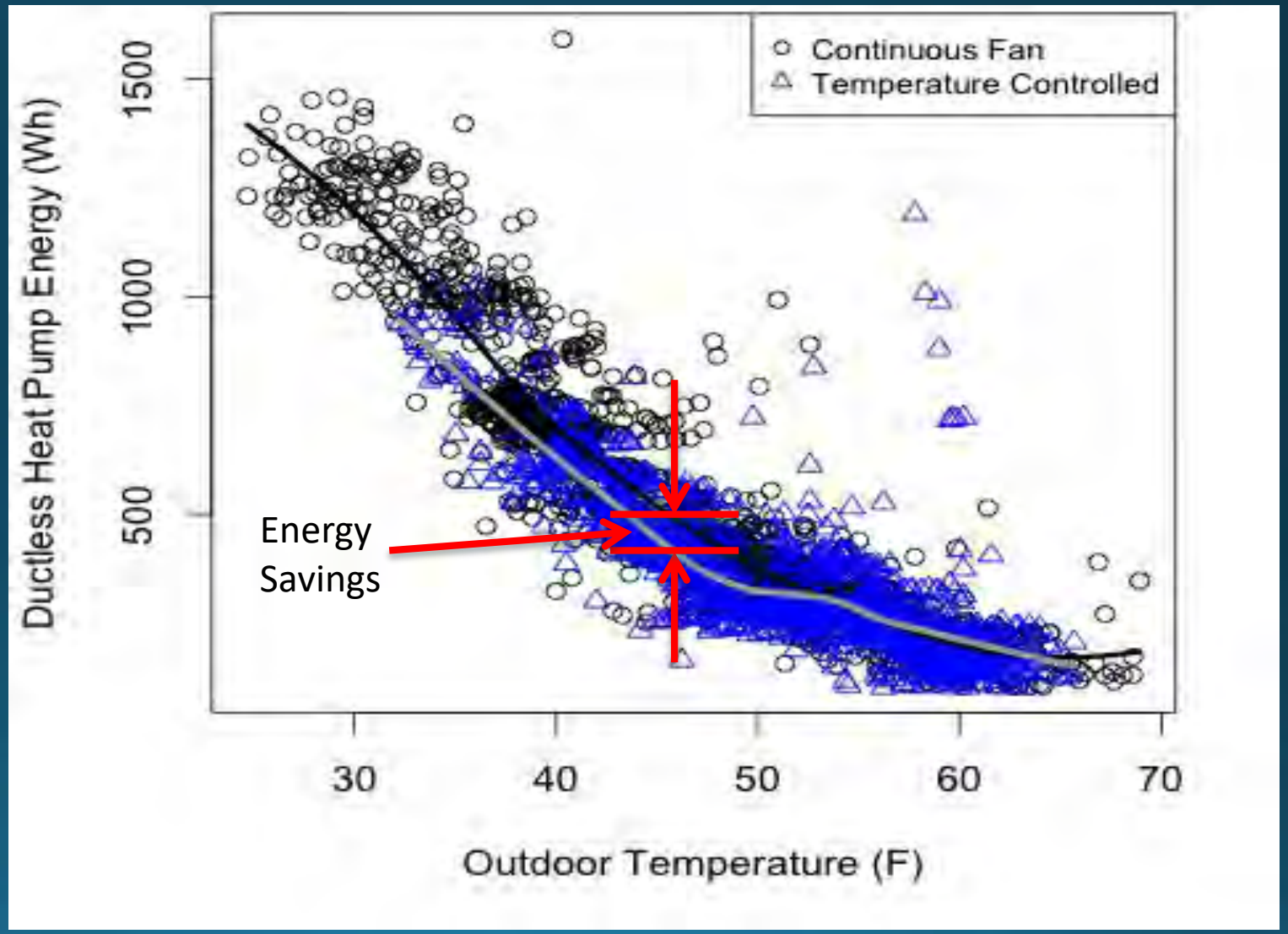



RIVEC Operation for the Hybrid System
Off during peak
Relative Exposure and Dose, and Stack ACH [/h]
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0
4
8
12
16
20
24
28
32
36
40
44
48
Time [h]
RIVEC Fan ON/OFF
Dryer ON/OFF
Rel Exp
Rel Dose
Occ Exp
Occ Dose
Occupied
Stack ACH

Simplified control: Temperature Cut-off

Temperature Controlled Ventilation

- Simple cut-off Temperature
- Pre-calculate bigger fan, using EQUIVALENCY and historical weather
- Turn fan on and off depending on measured outdoor temperature
  - Could be onsite – but better to use internet

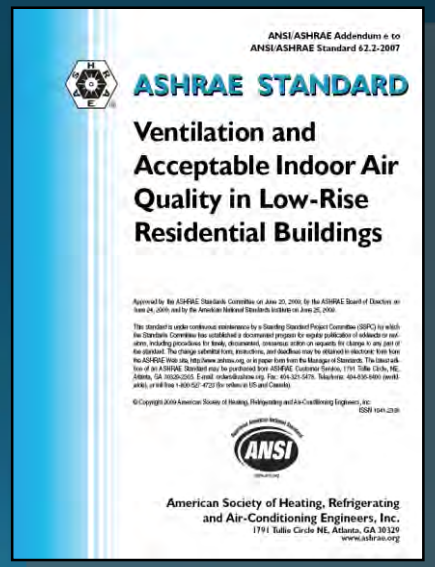


SMART CONCLUSIONS

- Smart Ventilation Can…
  - Cut ventilation energy
    - by up to a factor of 2
  - Optimize other quantities
    - Peak power; comfort; outdoor air expose
  - Meet programmatic need
    - Integrated or retrofit
- Smart Ventilation Cannot…
  - Be bought of the shelf today, but maybe soon

What's Smart to do Next?

- Occupancy-based smart controls
- ASHRAE 62.2-2016 includes equivalency
- Have smart ventilation incorporated into energy codes and home energy ratings
- Commercialization:
  - First implementers – supply ventilation in Multi-Family Buildings with measured T and RH in inlet air
  - Much interest from controls and HVAC equipment manufacturers (mostly waiting to see about getting credit in codes and standards)



LOOKING FORWARD

- Ventilation Must Continue to Get Smarter
  - We can dilute contaminants in ways that use less energy, create less problems for occupants, utilities and the environment.
- IAQ Must Get Quantitative
  - We need quantitative metrics for health & IAQ that will allow a variety of solutions.
- Reduce the Importance of Ventilation, eventually
  - Dilution should be the *last* choice to provide health.
- All priorities for us

VENTILATION SCIENCE BICENTENNIAL

- *Purpose:* To honor 200 years of ventilation science
- *Proposed Host:* CIBSE
- *Proposed Date:* April 3, 2034
- *Proposed Location*: Palace of Westminster
- *Proposed Topic:* Eulogy for Ventilation Rates

Questions?