1

Learning Objectives

- To understand the role of proper indoor humidification in improving health and cognitive functioning
- To understand that proper indoor humidification can be an intervention to prevent seasonal influenza spread in preschools
- To understand how to properly design a high-pressure fogging system for health-care applications both for humidification and energy saving
- **To understand how to estimate the break-even point of the most common steam and adiabatic humidification systems**

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2

Acknowledgements & Bias

- Chris Habets, B.Eng., P.Eng., LEED AP BD+C, CEA Business Development Manager – Energy and Sustainability, Condair Ltd.

- Bias: the author works for CAREL industries SpA, maker of humidification systems, HVAC/R controllers and monitoring systems

3

Agenda

1. Climatic zones (cities)
2. Conditioned spaces
3. AHU structure
4. Humidifiers:
   Steam: **electrodes**, **electric resistance**, **gas-fired**
   Adiabatic: **pressurized-water**, **wetted media**, **ultrasonic**
5. Resource costs: energy, water, labour
6. Costs & break-even points:
   1. CAPEX: purchase, installation, commissioning
   2. OPEX of the AHU: electricity, water, annual service (labour), annual spare parts
7. Conclusions

4

Climatic zones (cities)

- Selected some Global Environmental Zones [2] as representative weather conditions

- **Atlanta, GA**: hot temperate & mesic (GEZ K11)
  Mesic = with a moderate or well-balanced supply of moisture

- **Boise, ID**: cool temperate and xeric (GEZ I5)
  Xeric = receiving only a small amount of moisture (< 250 mm/10 in of annual precipitation)

- **Las Vegas, NV**: hot & dry (GEZ N3)

- **Minneapolis, MN**: cool temperate and dry (GEZ H9)

5

Conditioned spaces

- Selected as representative conditioned spaces

- **Office**:
  - 100 persons
  - Set point: 72 °F (22 °C) 40 %rh @ CAV 7,475 cfm, 394 ft/s (12,700 m³/h, 2 m/s)
  - Duty: 8am–8pm, Mon–Fri, Jan-Dec

- **Hospital**:
  - 5000 persons
  - Set point: 72 °F (22 °C) 40 %rh @ CAV 370,863 cfm, 394 ft/s (630,100 m³/h, 2 m/s)
  - Duty: 24/7/365

CAV = Constant Air Volume

6

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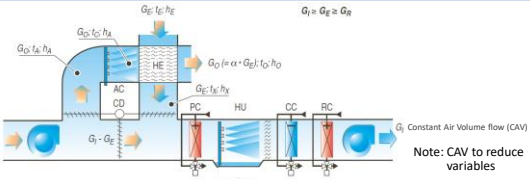
AHU structure (CAV)



Note: CAV to reduce variables

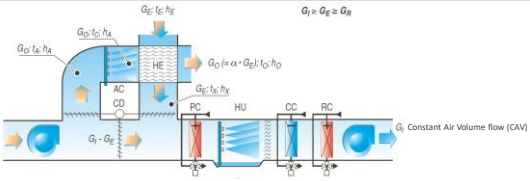
CD	Combined dampers	HE	Heat exchanger
PC	Preheating coil	G_I	Total air flow-rate
HU	Humidifier	G_E	Outside air flow-rate
CC	Cooling coil	G_{vent}	Minimum renewal air flow-rate
RC	Post-heating coil	G_O	Exhaust air flow-rate
AC	Adiabatic cooler (OFF)	α	Ratio between G_O and G_E

Outside air ➔ ODA

α = 1, exhaust flow = ODA

7

AHU structure: devices



CD	Combined dampers	HE	Heat exchanger
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AC	Adiabatic cooler (OFF)	α	Ratio between G_O and G_E

Outside air ➔ ODA

α = 1, exhaust flow = ODA

Blowers: fixed speed (CAV)
Mixing box: 20%–100% ODA & 100% ODA
HE: efficiency 60%, no by-pass

AC: OFF to reduce variables
Coils: modulating
HU: the only changing device across simulations

8

Estimation algorithm

- *Traditional:*
  - *The humidifier is sized based on a reference outdoor humidity (driest)*
  - *AHU running costs are a consequence*
  - *They may not be the minimum because they are a consequence of a humidifier sized "beforehand"*
  - *This method has not been used here*
- Used for this presentation:
  - Devices are freely modulated to approach the space set point, while **minimizing the AHU's electricity + water costs**, the AHU's primary energy input, the water usage, and maximizing the ODA %
  - The humidifier size is a consequence of the minimum running costs
  - This guarantees that the humidifier corresponds to the AHU min. costs
  - Note: humidification loads vary according to the type of humidifier (costs of energy source, water usage, pressure drops)

9

Estimations

- 96 estimations to calculate:
  - CAPEX of the humidifier: purchase (list price) + installation
  - OPEX of the AHU: energy + water + maintenance (labour & spares)
    Note: no inflation, no interest rates included (simpler to understand)
- Same AHU
- **What changes**:
  - Humidifier types (6): steam (3x) + adiabatic (3x)
  - Climatic zones (4 cities): 2-°F bin data according to spaces' duties
  - Conditioned spaces (2): office, hospital
  - 2 cases of mixing of outdoor air (ODA) with recirculation air:
    - 20%-100% ODA, modulating
    - 100% (fully ODA), non-modulating
- Not considered:
  - Precision requirements
  - Hygiene requirements
  - Energy source and water availability
  - Anything else not "economic"

10

Humidification systems: steam

TYPE	INSTALL. 1 unit/2+ units	POWER CONS.	MODUL.	WATER	ANNUAL LABOUR	ANNUAL SPARES
ELECTRODES	4/2 hrs	0.75 kW_{el}/(kg/h) 0.34 kW_{el}/(lb/hr)	20%–100%	MAINS	(2x 4 hrs)/yr	120–600 USD/yr
EL. HEATERS	4/2 hrs	0.75 kW_{el}/(kg/h) 0.34 kW_{el}/(lb/hr)	1%–100%	MAINS, **RO** RO ≤ 50 µS/cm, rec. factor = 50%	(1x 4 hrs)/yr	655–710 USD/yr Note: annualized ave. cost of a typ. 5-yr. period
GAS-FIRED	8/6 hrs	0.75 kW_{th}/(kg/h) 0.34 kW_{th}/(lb/hr)	25%–100%	MAINS, **RO** RO ≤ 50 µS/cm, rec. factor = 50%	(1x 6 hrs)/yr	1035–1050 USD/yr Note: annualized ave. cost of a typ. 5-yr. period

Values are per humidifier
Rec. factor = Recovery factor = ratio outlet water (demineralized) / inlet water (typ. mains)

11

Humidification systems: adiabatic

TYPE	INSTALL. 1 unit/2+ units	POWER CONS.	MODUL.	WATER	ANNUAL LABOUR # times x hrs/yr.	ANNUAL SPARES [USD/yr.]
PRESSURIZED -WATER	12/8 hrs	10 W_{el}/(kg/h) 5 W_{el}/(lb/hr) Plus pressure drop	15%–100%	MAINS, **RO** RO ≤ 50 µS/cm, rec. factor = 50%	(3x 4 hrs)/yr	1135–2350 USD/yr Note: oil & valves of pump + annualized ave. cost for RO
WETTED MEDIA	10-72 hrs*	1.4 W_{el}/(kg/h) 0.6 W_{el}/(lb/hr) Plus pressure drop	20%-100%	MAINS, RO	(4x 2 hrs)/yr + (1x 4 hrs)/yr to (4x 4 hrs)/yr + (1x 16 hrs)/yr*	400-12000 USD/yr* Note: annualized ave. cost of a typ. 3-yr. period
ULTRASONIC	4/3 hrs	70 W_{el}/(kg/h) 32 W_{el}/(lb/hr)	1%–100%	RO ≤ 5 µS/cm Rec. factor = 10%	(2x 4 hrs)/yr	1035–2050 USD/yr Note: annualized ave. cost of a typ. 5-yr. period

*: wetted media are installed as 1 piece (not 2+) and the values vary according to its size
Rec. factor = Recovery factor = ratio outlet water (demineralized) / inlet water (typ. mains)

12

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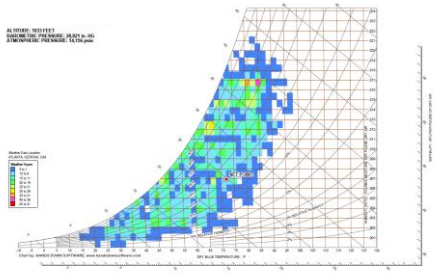
Resources: costs

- Electricity: 0.1 USD/kWh_{el}
- Gas (LPG): 10 USD/1000 ft^3 ≅ 0,0374 USD/kWh_{th}
- Water: 1 USD/1000 gallons ≅ 0,264 USD/m^3
- Labour: 100 USD/hr

13

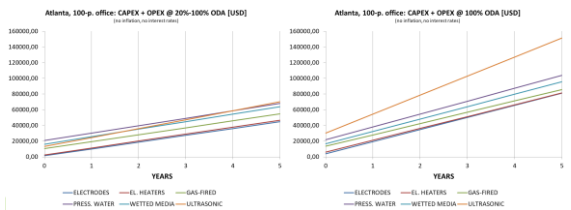
Atlanta, GA, 100-person office: climatic conditions vs. set point



14

Atlanta, GA, 100-person office: sizes and break-even points

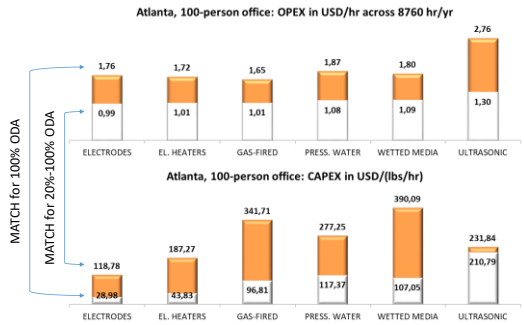
SIZE (lbs/hr)	ELECTRODES	HEATERS	GAS-FIRED	PRESS. WATER	WETTED MEDIA	ULTRASONIC
20%-100% ODA	15	15	33	79	44	60
100% ODA	148	148	148	196	165	150
BOLD RED = MOST CONVENIENT						



15

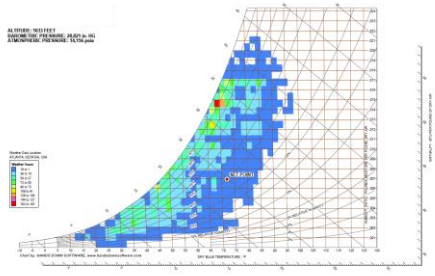
Atlanta, GA, 100-person office: OPEX & CAPEX

- OPEX: multiply by 8760 to get the approx. annual AHU OPEX
- CAPEX: multiply by actual lbs/hr to get the approx. humidifier CAPEX



16

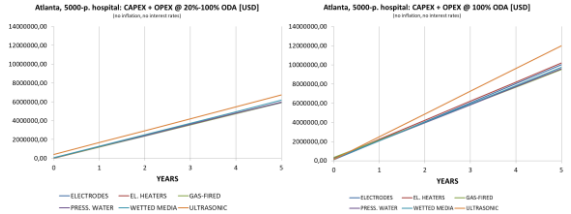
Atlanta, GA, 5000-person hospital: climatic conditions vs. set point



17

Atlanta, GA, 5000-person hospital: sizes and break-even points

SIZE (lbs/hr)	ELECTRODES	HEATERS	GAS-FIRED	PRESS. WATER	WETTED MEDIA	ULTRASONIC
20%-100% ODA	267	267	313	2055	1543	2053
100% ODA	7048	7048	7038	7075	9259	7075
BOLD RED = MOST CONVENIENT						



18

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Atlanta, GA, 5000-person hospital

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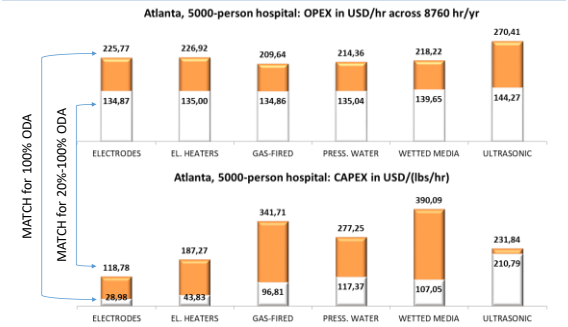
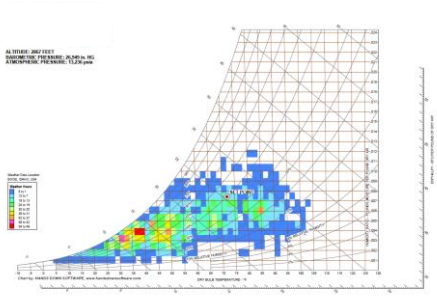


19

Boise, ID, 100-person office: climatic conditions vs. set point

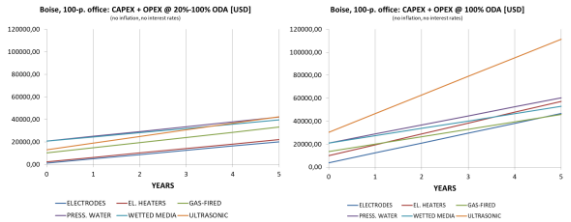


20

Boise, ID, 100-person office: sizes and break-even points

SIZE (lbs/hr)	ELECTRODES	HEATERS	GAS-FIRED	PRESS. WATER	WETTED MEDIA	ULTRASONIC
20%-100% ODA	18	22	40	73	44	62
100% ODA	185	185	181	152	176	152

BOLD RED = MOST CONVENIENT



21

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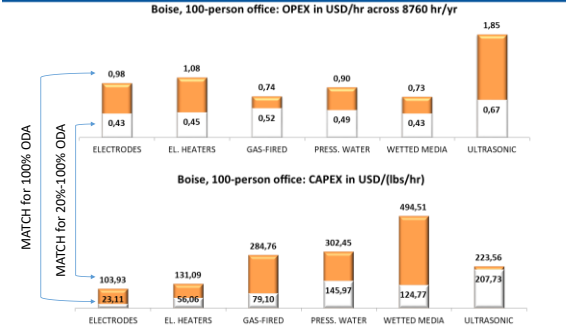
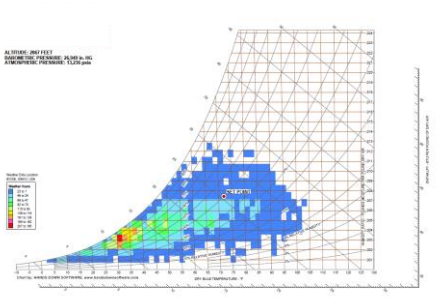


22

Boise, ID, 5000-person hospital: climatic conditions vs. set point

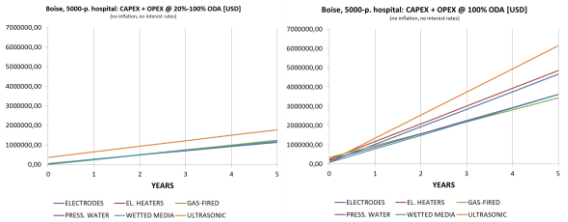


23

Boise, ID, 5000-person hospital: sizes and break-even points

SIZE (lbs/hr)	ELECTRODES	HEATERS	GAS-FIRED (100% ODA)	PRESS. W. (20%-100% ODA)	WET	ULTRASONIC
20%-100% ODA	293	293	293	2004	1764	1916
100% ODA	6975	6975	7297	7006	9039	6995

BOLD RED = MOST CONVENIENT



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Boise, ID, 5000-person hospital

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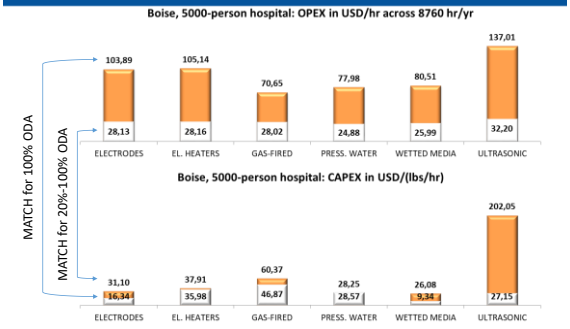
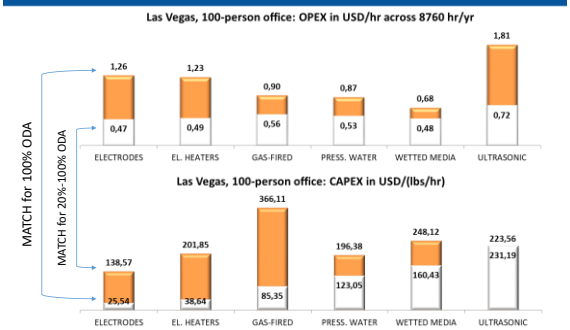


25

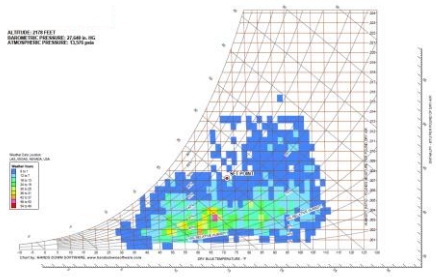
Las Vegas, NV, 100-person office: OPEX & CAPEX

- OPEX: multiply by 8760 to get the approx. annual AHU OPEX
- CAPEX: multiply by actual lbs/hr to get the approx. humidifier CAPEX



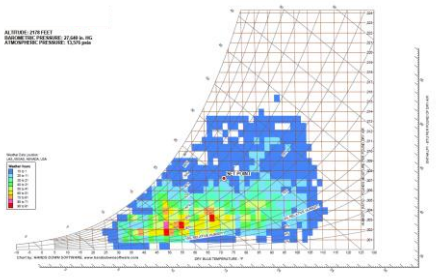
28

Las Vegas, NV, 100-person office: climatic conditions vs. set point



26

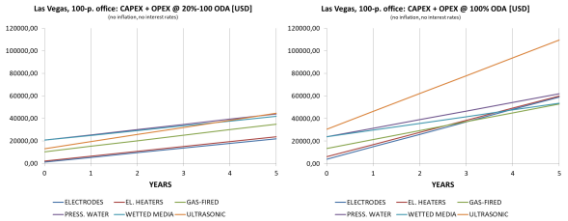
Las Vegas, NV, 5000-person hospital: climatic conditions vs. set point



29

Las Vegas, NV, 100-person office: sizes and break-even points

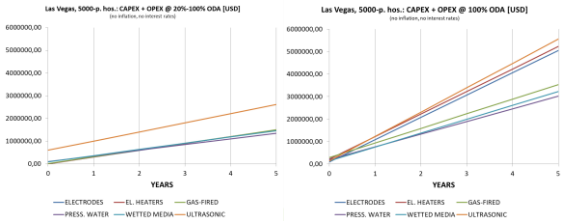
SIZE (lbs/hr)	ELECTRODES (20%-100% ODA)	HEATERS	GAS-FIRED (100% ODA)	PRESS. WATER	WET M. (100% ODA)	ULTRASONIC
20%-100% ODA	**13**	13	31	112	88	62
100% ODA	**168**	168	168	203	154	137
BOLD RED = MOST CONVENIENT						



27

Las Vegas, NV, 5000-person hospital: sizes and break-even points

SIZE (lbs/hr)	ELECTRODES	HEATERS	GAS-FIRED	PRESS. WATER	WETTED MEDIA	ULTRASONIC
20%-100% ODA	97	97	97	**3571**	3307	3100
100% ODA	6012	6012	6151	**6067**	6173	6067
BOLD RED = MOST CONVENIENT						



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Las Vegas, NV, 5000-person hospital

- OPEX: multiply by 8760 to get the approx. annual AHU OPEX
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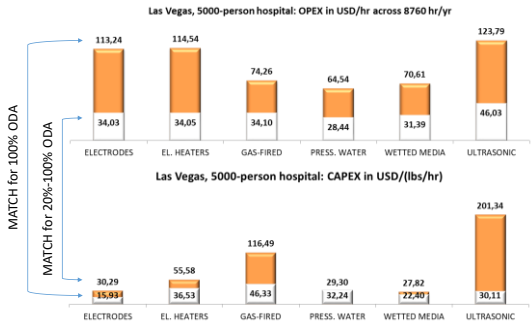
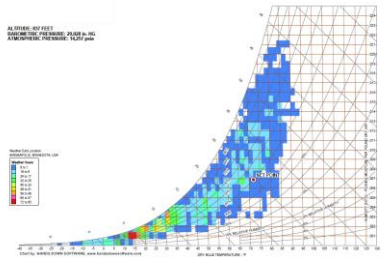


31

Minneapolis, MN, 100-person office: climatic conditions vs. set point

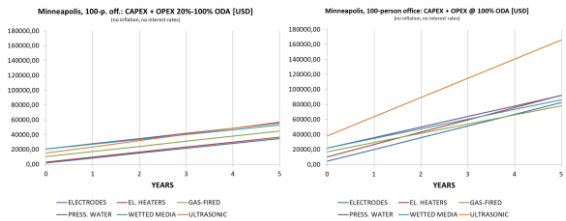


32

Minneapolis, MN, 100-person office: sizes and break-even points

SIZE (lbs/hr)	ELECTRODES (20%-100% ODA)	HEATERS	GAS-FIRED (100% ODA)	PRESS. WATER	WETTED MEDIA	ULTRASONIC
20%-100% ODA	**37**	37	**29**	79	88	64
100% ODA	**205**	205	**205**	179	220	179

BOLD RED = MOST CONVENIENT



33

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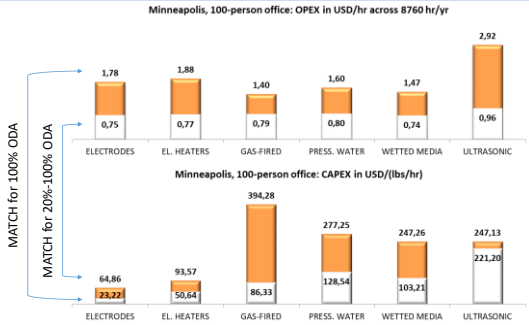
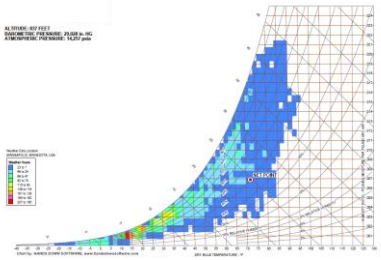


34

Minneapolis, MN, 5000-person hospital: climatic conditions vs. set point

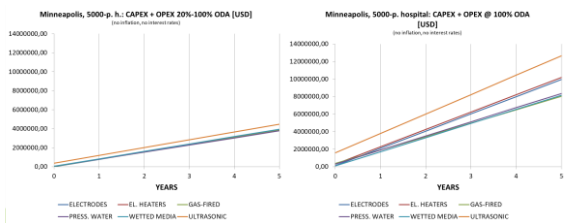


35

Minneapolis, MN, 5000-person hospital: sizes and break-even points

SIZE (lbs/hr)	ELECTRODES	HEATERS	GAS-FIRED	PRESS. WATER	WETTED MEDIA	ULTRASONIC
20%-100% ODA	556	556	**556**	**1922**	**1984**	1907
100% ODA	8228	8228	**8228**	**10240**	**10141**	8203

BOLD RED = MOST CONVENIENT



36

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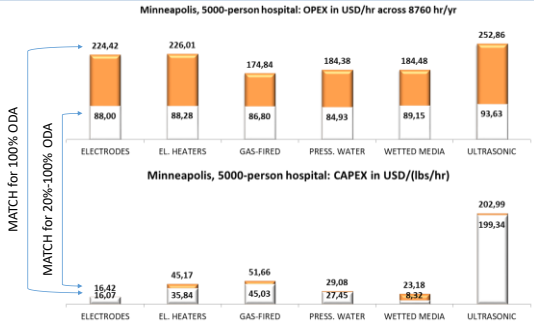
Minneapolis, MN, 5000-person hospital

- OPEX: multiply by 8760 to get the approx. annual AHU OPEX
- CAPEX: multiply by actual lbs/hr to get the approx. humidifier CAPEX



37

Conclusion

- The running costs (energy + water) of a reference AHU have been minimized by freely modulating its devices based on the climatic conditions of 4 representative cities (Atlanta, Boise, Las Vegas, Minneapolis) and 2 installations (100-person office & 5000-person hospital)
- Humidifiers (3x steam + 3x adiabatic) have been sized as a consequence
- The specific humidifier CAPEX, as USD/(lbs/hr), and AHU OPEX, as USD/hr, have been presented
- In general:
  - Offices, i.e. "small" loads (approx. up to 200 lbs/hr):
    - Immersed-electrodes systems often result as the most convenient given the lowest CAPEX, although the OPEX may be higher due to the electricity consumption
    - Gas-driven and wet media are convenient in dry climates (e.g., Las Vegas) due to the longer running hours
  - Hospitals, i.e. "big" loads (above 200 lbs/hr): gas-driven, pressurized water due to the longer running hours
- In case of equivalence, consider also: hygienic issues, precision required, energy source and water availability

38

Bibliography

1) ASHRAE Handbook 2016 – HVAC Systems and Equipment, Chapter 22 "HUMIDIFIERS"
2) "A high-resolution bioclimate map of the world: a unifying framework for global biodiversity research and monitoring", Marc J. Metzger et al., © 2012 Blackwell Publishing Ltd., DOI: 10.1111/geb.12022

39

Questions?

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40

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