2017 Winter Conference
Las Vegas, Nevada

Melanie M. Derby
Kansas State University
derbym@ksu.edu
(785)-532-2606

# Seminar 1: Updating Scientific Evidence about the Effects of Low Humidity on People

**RP–1630, "Update the Scientific Evidence for Specifying Lower Limit Relative Humidity Levels for Comfort, Health and IEQ in Occupied Spaces"**

## Learning Objectives

1. Understand the effects of humidity on health, comfort, IAQ and on elderly people
2. Understand that healthcare associated infections increase when the humidity decreases too much
3. Understand the human physiological reactions to low humidity
4. Understand the effects of low humidity on working performance

*ASHRAE is a Registered Provider with The American Institute of Architects Continuing Education Systems. Credit earned on completion of this program will be reported to ASHRAE Records for AIA members. Certificates of Completion for non-AIA members are available on request.*

This program is registered with the AIA/ASHRAE for continuing professional education. As such, it does not include content that may be deemed or construed to be an approval or endorsement by the AIA of any material of construction or any method or manner of handling, using, distributing, or dealing in any material or product. Questions related to specific materials, methods, and services will be addressed at the conclusion of this presentation.

## Acknowledgements


- Maryam Hamehkasi and Ronaldo Maghirang, Department of Biological and Agricultural Engineering, KSU
- Steven Eckels and Byron Jones, Department of Mechanical and Nuclear Engineering, KSU
- Grace M. Hwang, Johns Hopkins University Applied Physics Laboratory
- David Shulan, M.D., Allergist (retired), FL
- TC 5.11 and PMS (Roger Pasch, chair)

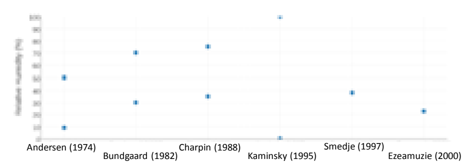

## Literature Search Approach

- Update Sterling (1985) paper; focus on post-1985 papers
- Keyword and citation searches
- Around 600 papers located
- General criteria for further paper analysis included:
  - At least one data point where RH ≤ 40%
  - New data
  - Report temperature
  - Controlled study
  - Focus on healthy, human subjects
  - Residences and workplaces
- Papers categorized in Health, Comfort, Indoor Environmental Quality (IEQ) categories

# Health

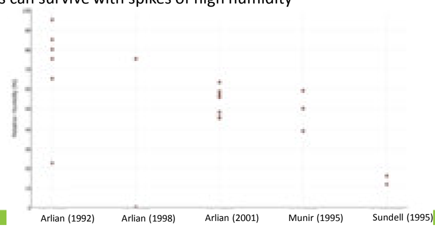
## Asthma and Respiratory

- Few laboratory studies [Andersen(1974), Bundgaard (1982), Kaminsky (1995)]
  - Warm, moist air and cold, dry air to determine mechanisms of exercise-induced asthma
- Environmental studies regarding the allergy/asthma link [Smedje(1997), Ezeamuzie (2000)]
- Very limited data available regarding low humidity



## House Dust Mites (HDM)

- Laboratory tests [Arlian (1992), Arlian (1998)]
  - Dust mites
- Controlled tests in homes [Arlian (2001)]
- Environmental tests [Munir (1995), Sundell (1995)
  - Sundell (1995)- ventilation is a confounding variable
- Low humidity (RH<60%) beneficial for reducing dust mite allergens; dust mites can survive with spikes of high humidity

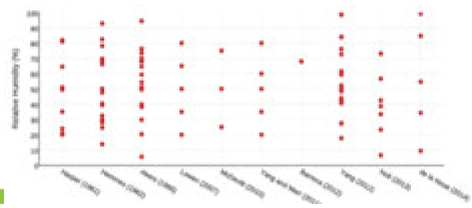



## Bacteria

- Lab tests
  - Aerosol viability [Dunklin (1948), Wright (1968), Theunissen (1993), and Ko (2000] and fomites [Lopez (2013)]
- Challenging to compare across studies
- What is the relationship between survival and infection?
- A few older studies still cited in literature


## Viruses

- Majority of data on influenza virus aerosol survival and transmission
- Laboratory testing [Akers (1966), de la Noue (2014), Lowen (2007), Noti (2013), Yang (2012)]
- Epidemiology [Barreca (2012), Jaakkola (2014), van Noort (2012)]
- Modeling [Yang (2011), Shaman (2009)]
- Influenza survival was a strong function of humidity and exhibited a canonical dip between 40%–80% RH



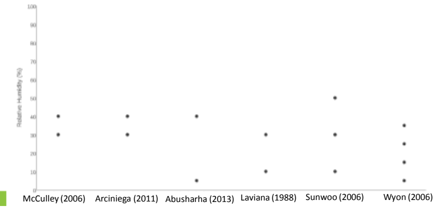
## Health Knowledge and Gaps

- Influenza and dust mite survival are strong functions of RH
- Limited asthma data
- Several routes of bacterial/virus transmission and infection hypothesized
  - Direct contact, fomite, droplet, droplet nuclei
  - Relative humidity can uniquely affect each of these transmission modes.
  - Bacteria envelope (Gram-positive or Gram-negative) affects RH, but even in these subcategories, the behavior at low humidities varies
- Many confounding variables
  - Air exchange rate, length of organism exposure, variation in the biological structure and routes of entry, variation of pathogen survival on different fomites, and variances in human host response
  - Several studies assumed that detection correlates with infection, while other studies were based on transmission rates

# Comfort

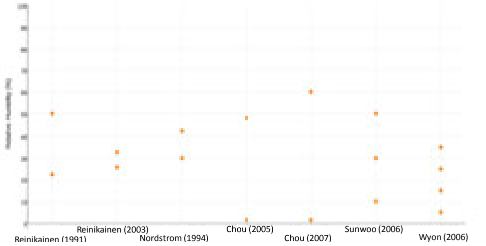
## Eye Irritation

- Focus on healthy patients
- Eye goggles [e.g., Arciniega (2011) and McCulley (2006)] and environmental chamber [e.g., Abusharha (2013), Laviana (1988), Sunwoo (2006), Wyon (2006)]
- Wyon (2006): eyes were drier at 5% RH than 35% RH although subjects did not perceive it; small but significant decrease in performance of office tasks at low RH



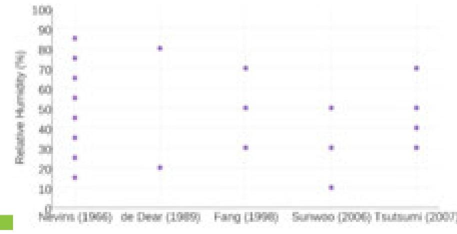
## Skin Irritation

- Focus on healthy patients
- Testing in offices/workplaces [e.g., Reinikainen (1991), Reinikainen (2003), Nordstrom (1994), Chou (2005), Chou (2007)] and environmental chambers [e.g., Sunwoo (2006) and Wyon (2006)]
- Increased transepidural water loss (TEWL) at lower RH, but changes with time are not known. How does the body adapt?




## Thermal Comfort

- Extensive testing in environmental chambers [e.g., Nevins (1966), de Dear (1989), Fang (1998), Sunwoo (2006), Tsutsumi (2007)]
- Few effects of low RH on thermal comfort as long as temperature is suitably adjusted for the humidity effect



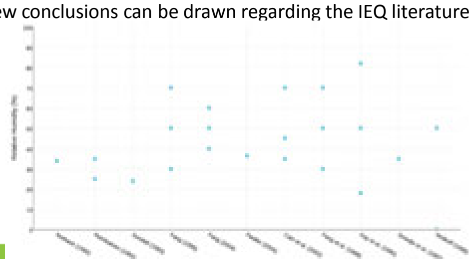

## Comfort Knowledge and Gaps

- Low humidity does not cause thermal discomfort in terms of thermal sensation
- Comfort effects of low humidity attributed to skin, eye, and mucous membrane irritation.
  - Evaporative tear losses increase and blink frequencies are higher in healthy eyes (minutes to hours)
  - What are the long term effects of low RH on vision, eye comfort, and eye health?
  - Increased skin discomfort and itching was observed at ultra-low humidity levels (1.5–2.5% RH)
  - Mild skin discomfort effects were observed for healthy patients in humidity ≤ 30% RH
  - Data suggest that initial TEWL was when a subject entered a low humidity condition, after which the skin adapted (in a time scale of 30–60 minutes) in order to conserve water in the short term.

# IEQ

## Indoor Air Quality (IAQ)

- Human subjects [e.g., Kay (1990), Fang (1998), Cain (2002), Fang (2004)], emissions from building materials [e.g., Wolkoff (1998), Fang (1999), Cain (2002)], and surveys [e.g., Norback (1990), Reinikainen (1992), Sundell (1993), Smedje (1997), Fiedler (2005)]
- Few conclusions can be drawn regarding the IEQ literature



## IEQ Knowledge and Gaps

- Limited data
- Results on the effects of RH on volatile organic compound (VOC) emissions from building materials were inconclusive
  - Depended on the type of material and type of VOC.
- Emissions from materials may or may not change with changes in temperature and humidity
- In general, increases in temperature and humidity decreased the perceived quality or acceptability of the air
- In the study by Cain et al. (2002), dilution (concentration) and temperature had far stronger effect than RH on TVOC emissions and perceived air quality

## Human Subjects

- Human subjects in surveys and laboratory tests

| Category | Children (0-13) | Adolescents (13-18) | University students only | Adults (18-65) | Elderly (>65) |
|---|---|---|---|---|---|
| Asthma/ Respiratory | 3 | 1 | 1 | 3 | 1 |
| House Dust Mites | 1 | 0 | 0 | 0 | 0 |
| Viruses/ Bacteria | 1 | 2 | 0 | 4 | 1 |
| Comfort | 0 | 0 | 8 | 5 | 1 |
| IEQ | 0 | 0 | 4 | 8 | 0 |

- Few studies addressed adults > 65 [e.g., Sunwoo (2006)- 8 college age men, 8 men (avg age 72)]

## Conclusions and Future Work

- Most studies involving human subjects conducted tests at a limited number of humidity levels (e.g., 2-3)
- Few studies identified the direct benefits or consequences of increasing relative humidity by 10%, for example
- Confounding variables included ventilation rates and exposure time
- For building occupants, what are the appropriate weightings of the comfort, health, and IEQ categories?

## Bibliography


Derby, M. M., M. Hamehkasi, S. Eckels, G.M. Hwang, B. Jones, R. Maghirang, D. Shulan. (2016). "Update of the scientific evidence for specifying lower limit relative humidity levels for comfort, health, and indoor environmental quality in occupied spaces (RP-1630)." <u>Science and Technology for the Built Environment: 1-16.</u>

E. Sterling, A. Arundel, T. Sterling, Criteria for human exposure to humidity in occupied buildings, ASHRAE Transactions, 91 (1B) (1985) 611-622.

**Asthma:**

Andersen, G.R. Lundqvist, P.L. Jensen, D.F. Proctor, Human response to 78-hour exposure to dry air, Archives of Environmental Health: An International Journal, 29 (6) (1974) 319-324.

Bundgaard, T. Ingemann-Hansen, A. Schmidt, J. Halkjaer-Kristensen, Influence of temperature and relative humidity of inhaled gas on exercise-induced asthma, European Journal of Respiratory Diseases, 63 (3) (1982) 239-244.

D.A. Kaminsky, C.G. Irvin, D.A. Gurka, D.C. Feldsien, E.M. Wagner, M.C. Liu, S.E. Wenzel, Peripheral airways responsiveness to cool, dry air in normal and asthmatic individuals, American Journal of Respiratory and Critical Care Medicine, 152 (6) (1995) 1784-1790.

G. Smedje, D. Norbäck, C. Edling, Asthma among secondary schoolchildren in relation to the school environment, Clinical & Experimental Allergy, 27 (11) (1997) 1270-1278.

C. Ezeamuzie, M. Thomson, S. Al-Ali, A. Dowaisan, M. Khan, Z. Hijazi, Asthma in the desert: spectrum of the sensitizing aeroallergens, Allergy, 55 (2) (2000) 157-162.


## Bibliography


**HDM**

L.G. Arlian, Water balance and humidity requirements of house dust mites, Experimental & Applied Acarology, 16 (1-2) (1992) 15-35.

L.G. Arlian, J.S. Neal, S.W. Bacon, Survival, fecundity, and development of Dermatophagoides farinae (Acari: Pyroglyphidae) at fluctuating relative humidity, Journal of Medical Entomology, 35 (6) (1998) 962-966.

L.G. Arlian, J.S. Neal, M.S. Morgan, D.L. Vyszenski-Moher, C.M. Rapp, A.K. Alexander, Reducing relative humidity is a practical way to control dust mites and their allergens in homes in temperate climates, Journal of Allergy and Clinical Immunology, 107 (1) (2001) 99-104.

Munir, B. Bjorksten, R. Einarsson, A. Ekstrand-Tobin, C. Moller, A. Warner, N.I. Kjellman, Mite allergens in relation to home conditions and sensitization of asthmatic children from three climatic regions, Allergy, 50 (1) (1995) 55-64.

J. Sundell, M. Wickman, G. Pershagen, S. Nordvall, Ventilation in homes infested by house-dust mites, Allergy, 50 (2) (1995) 106-112.

**Bacteria**

E.W. Dunklin, T.T. Puck, The lethal effect of relative humidity on air-borne bacteria, Journal of Experimental Medicine, 87 (2) (1948) 87-101.

D. Wright, G. Bailey, M. Hatch, Role of relative humidity in the survival of airborne Mycoplasma pneumoniae, Journal of Bacteriology, 96 (4) (1968) 970-974.

H. Theunissen, N.A. Lemmens-den Toom, A. Burggraaf, E. Stolz, M. Michel, Influence of temperature and relative humidity on the survival of Chlamydia 89 pneumoniae in aerosols, Applied and Environmental Microbiology, 59 (8) (1993) 2589-2593.

G. Ko, M. First, H. Burge, Influence of relative humidity on particle size and UV sensitivity of Serratia marcescens and Mycobacterium bovis BCG aerosols, Tubercle and Lung Disease, 80 (4) (2000) 217-228.

G.U. Lopez, C.P. Gerba, A.H. Tamimi, M. Kitajima, S.L. Maxwell, J.B. Rose, Transfer efficiency of bacteria and viruses from porous and nonporous fomites to fingers under different relative humidity conditions, Applied and Environmental Microbiology, 79 (18) (2013) 5728-5734.

**Viruses**

T. Akers, S. Bond, L. Goldberg, Effect of temperature and relative humidity on survival of airborne Columbia SK group viruses, Applied microbiology, 14 (3) (1966) 361-364.

A.C. de la Noue, M. Estienney, S. Aho, J.-M. Perrier-Cornet, A. de Rougemont, P. Pothier, P. Gervais, G. Belliot, Absolute humidity influences the seasonal persistence and infectivity of human norovirus, Applied and Environmental Microbiology, (2014) AEM. 01871-01814.

A.C. Lowen, J. Steel, Roles of humidity and temperature in shaping influenza seasonality, Journal of virology, (2014) JVI. 03544-03513.

J.D. Noti, F.M. Blachere, C.M. McMillen, W.G. Lindsley, M.L. Kashon, D.R. Slaughter, D.H. Beezhold, High humidity leads to loss of infectious influenza virus from simulated coughs, PLoS One, 8 (2) (2013) e57485.

W. Yang, S. Elankumaran, L.C. Marr, Relationship between humidity and influenza A viability in droplets and implications for influenza's seasonality, PloS One, 7 (10) (2012) e46789.

W. Yang, L.C. Marr, Dynamics of airborne influenza A viruses indoors and dependence on humidity, PLoS One, 6 (6) (2011) e21481.

A.I. Barreca, J.P. Shimshack, Absolute humidity, temperature, and influenza mortality: 30 years of county-level evidence from the United States, American Journal of Epidemiology, 176 (suppl 7) (2012) S114-S122.

K. Jaakkola, A. Saukkoriipi, J. Jokelainen, R. Juvonen, J. Kauppila, O. Vainio, T. Ziegler, E. Rönkkö, J.J. Jaakkola, T.M. Ikäheimo, Decline in temperature and humidity increases the occurrence of influenza in cold climate, Environmental Health, 13 (1) (2014) 22.

S.P. van Noort, R. Águas, S. Ballesteros, M.G.M. Gomes, The role of weather on the relation between influenza and influenza-like illness, Journal of Theoretical Biology, 298 (2012) 131-137.

J. Shaman, M. Kohn, Absolute humidity modulates influenza survival, transmission, and seasonality, Proceedings of the National Academy of Sciences, 106 (9) (2009) 3243-3248.


## Bibliography


**Eye Irritation**

J.C. Arciniega, J.C. Wojtowicz, E.M. Mohamed, J.P. McCulley, Changes in the evaporation rate of tear film after digital expression of meibomian glands in patients with and without dry eye, Cornea, 30 (8) (2011) 843-847.

J.P. McCulley, J.D. Aronowicz, E. Uchiyama, W.E. Shine, I.A. Butovich, Correlations in a change in aqueous tear evaporation with a change in relative humidity and the impact, American Journal of Ophthalmology, 141 (4) (2006) 758-760.

A.A. Abusharha, E.I. Pearce, The effect of low humidity on the human tear film, Cornea, 32 (4) (2013) 429-434.

J. Laviana, F. Rohles, P. Bullock, Humidity, comfort and contact lenses, ASHRAE Transactions, 94 (Part 1) (1988) 3-11.

Y. Sunwoo, C. Chou, J. Takeshita, M. Murakami, Y. Tochihara, Physiological and subjective responses to low relative humidity, Journal of Physiological Anthropology, 25 (1) (2006) 7-14.

D.P. Wyon, L. Fang, L. Lagercrantz, P.O. Fanger, Experimental determination of the limiting criteria for human exposure to low winter humidity indoors (RP-1160), HVAC&R Research, 12 (2) (2006) 201-213.

**Skin Irritation**

L.M. Reinikainen, J.J. Jaakkola, O.P. Heinonen, The effect of air humidification on different symptoms in office workers—An epidemiologic study, Environment International, 17 (4) (1991) 243-250.

L. Reinikainen, J. Jaakkola, Significance of humidity and temperature on skin and upper airway symptoms, Indoor Air, 13 (4) (2003) 344-352.

K. Nordström, D. Norbäck, R. Akselsson, Effect of air humidification on the sick building syndrome and perceived indoor air quality in hospitals: a four month longitudinal study, Occupational and Environmental Medicine, 51 (10) (1994) 683-688.

T.-C. Chou, K.-H. Lin, S.-M. Wang, C.-W. Lee, S.-B. Su, T.-S. Shih, H.-Y. Chang, Transepidermal water loss and skin capacitance alterations among workers in an ultra-low humidity environment, Archives of Dermatological Research, 296 (10) (2005) 489-495.

T.-C. Chou, K.-H. Lin, H.-M. Sheu, S.-B. Su, C.-W. Lee, H.-R. Guo, T.-N. Wu, H.-Y. Chang, Alterations in health examination items and skin symptoms from exposure to ultra-low humidity, International Archives of Occupational and Environmental Health, 80 (4) (2007) 290-297.

**Thermal Comfort**

R.G. Nevins, F.H. Rohles, W. Springer, A. Feyerherm, A temperature-humidity chart for thermal comfort of seated persons, ASHRAE Transactions, 72 (1) (1966) 283-291.

R. De Dear, H. Knudsen, P. Fanger, Impact of air humidity on thermal comfort during step-changes, ASHRAE Transactions, 95 (2) (1989) 336-350.

L. Fang, G. Clausen, P.O. Fanger, Impact of temperature and humidity on the perception of indoor air quality, Indoor Air, 8 (2) (1998) 80-90.

**IAQ**

D. Kay, D. Heavner, P. Nelson, R. Jennings, D. Eaker, J. Robinson, P. DeLuca, C. Risner, J. Brockschmidt, Effects of relative humidity on nonsmoker response to environmental tobacco smoke, Proceedings of Indoor Air, 90 (1990) 275-280.

W.S. Cain, R. Schmidt, B.P. Leaderer, J.F. Gent, Emission of VOCs from materials used in buildings: analytical and sensory aspects, ASHRAE Transactions, 108 (2002) 283.

L. Fang, D. Wyon, G. Clausen, P.O. Fanger, Impact of indoor air temperature and humidity in an office on perceived air quality, SBS symptoms and performance, Indoor Air, 14 (s7) (2004) 74-81.

N. Fiedler, R. Laumbach, K. Kelly-McNeil, P. Lioy, Z.-H. Fan, J. Zhang, J. Ottenweller, P. Ohman-Strickland, H. Kipen, Health effects of a mixture of indoor air volatile organics, their ozone oxidation products, and stress, Environmental Health Perspectives, (2005) 1542-1548.


## QUESTIONS?


Dr. Melanie Derby

derbym@ksu.edu

# Keywords

| Effects of low relative/absolute/specific humidity on: | Search terms |
|---|---|
| Comfort | Skin dryness, Thermal comfort, Comfort, Eye irritation, Static electricity |
| Health | Health effects, Bacteria, Virus, Influenza, Pneumonia, Asthma, Allergy, Eukaryotes, Eukarya, Metagenomics, Microbiome, Microbes, Microbial, Mites, Infections, Respiratory infections, Fungal Fungi, Allergic rhinitis, Physiological effects, 16s RNA |
| IEQ | Ozone generation, Particulate level, Particulate generation, PM2.5, bioaerosol |
| Population | Adolescents (13–18), Adults, Adults over 65 |