Human airways in context with indoor and outdoor climate
Technical Specification of human nose

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ABSTRACT

The bulk of literature on humans as occupants of buildings, is focused on comfort issues, especially thermal comfort. This review focuses on climate impacts on human airways and related health aspects.

The paper describes design specifications, capacities, and limitations of conducting airways. The focus will be on the crucial role of the nose for the conditioning of breathing air to the physiological requirements of gas exchange in the alveoli.

Throughout several million years of humankind's evolution, the nose adapted to extreme climate situations in terms of moisture and temperature conditions. Low absolute humidity (AH) was the climate factor with the greatest impact on the shape of human noses. Up to the present day, low AH is the crucial challenge for the vital air conditioning. Nose and bronchi of a growing aging population are over stressed with indoor winter conditions in temperate climate. The paper explains the potential consequences for infection defense and seasonal infections.

UPPER AND LOWER AIRWAYS AND A CRUCIAL INTERSECTION

In terms of functionality, airways may be divided in conducting airways (air conveying) from nares and lips to the 15th generation of bronchi and respiratory airways from the 16th generation of bronchi to the alveolar sacs, where gas exchange takes place . The first part of conducting airways, above the larynx, is a double duct where one duct (oropharynx) is shared as air and food pathway. The two pathways cross in the pharyngeal region Figure 4 (Lumb, 2017). The vocal cords mark the boundary between the doubled and shared upper airways and lower airways. The crossing of airways and foodways has far reaching consequences as will be shown.

The conducting airways are lined by a two layered mucosa type I with cilia bearing epithelial cells that are covered by a mucus layer, see Figure 3. Interposed between the respiratory epithelium of the nasal cavity and the conducting airways below vocal cords is a section of stratified, squamous epithelium of mucosa type II in the oropharynx. This epithelium is resistant to thermal, chemical, and mechanical stress factors due to the processing of a wide range of foodstuff. Moreover mucosa type II is specialized in handling resistance and tolerance against pathogens and commensals of the local microbiota in oropharynx (Man, de Steenhuijsen Piters, & Bogaert, 2017). It's innate and adaptive immune protective mechanisms differ from mucosa type I in nose cavity and lower conducting airways (Iwasaki, 2016). Besides, it lacks the mucociliary clearing system of respiratory airways. When confronted with airborne microbes, this might be a disadvantage and offer airborne microbes a preferential point of entry. The high viral concentrations in pharyngeal swabs of SARS-CoV-2 viruses and their predictive value for the severity of COVID-19 (Silva et al., 2021) seem to support this suspicion.

CONDUCTING AIRWAYS MUST GUARANTEE HOMEOSTASIS OF RESPIRATORY AIRWAYS

Conducting airways decouple respiratory airways from the potentially devastating influence of ambient air. In tidal nose breathing, nose, oropharynx and trachea protect the mucosal homeostasis of the lower conducting airways and the vital gas exchange by delivering moisture saturated breathing air of 37°C core temperature below the trachea bifurcation (Williams, Rankin, Smith, Galler, & Seakins, 1996). This important level for airways homeostasis is called isothermic saturation boundary (ISB), Figure 4. Along the mucosal surface a bi-directional exchange of water and heat with inhaled and exhaled air takes place, Graph 1, (Naclerio, Pinto, Assanasen, & Baroody, 2007; Naftali, Rosenfeld, Wolf, & Elad, 2005; Williams et al., 1996; Wolf, Naftali, Schroter, & Elad, 2004). On its way down to the ISB inhaled air reaches saturation of 44mg/l and is heated up to 37°C (Williams et al., 1996). During exhalation less than one third of water and heat is regained (Walker, Wells, & Merrill, 1961), Graph 2. Homeostasis and functionality of the mucosa below the ISB is optimal when exposed to saturated air of core temperature (Williams et al., 1996). When inspired air deviates from the optimal level, progressive dysfunction occurs (Williams et al., 1996).

AIR CONDITIONING BY UPPER AIRWAYS

Air conditioning by conducting airways is a complex and highly variable task with impact on acute and chronic lung diseases and infections (Anderson et al., 2015; Arundel, Sterling, Biggin, & Sterling, 1986; Brian Button, Anderson, & Boucher, 2016; Gallo, Locatello, Mazzoni, Novelli, & Annunziato, 2021; Hill et al., 2014; Kukwa et al., 2018; Lee, Guilleminault, Chiu, & Sullivan, 2015; Moriyama, Hugentobler, & Iwasaki, 2020; Naclerio et al., 2007; Pinto & Jeswani, 2010; Williams et al., 1996). The task depends on the conditioning capacity of the nose, breathing mode, respiratory volume and on absolute humidity (AH) of indoor air (see below). Nose breathing is the common, physiologic breathing mode at rest with unblocked nose. Mouth breathing reduces the workload for respiration due to lower resistance (Lumb, 2017). Nevertheless, forced mouth breathing has profound negative consequences on oral, dental and craniofacial development in childhood that are not fully understood (Lee et al., 2015). Exclusive mouth breathing at rest eliminates the two essential purposes of the nose: air-conditioning and protection against airborne pathogens. An increased risk of upper respiratory tract infections (Kukwa et al., 2018) and exposure to air pollutants (Brown, Zeman, & Bennett, 2001; Everard, Hardy, & Milner, 1993) are the consequences. The paired nose cavities are specialized in air conditioning (Keck, Rozsasi, & Gruen, 2011; Naclerio et al., 2007; Naftali et al., 2005; Wolf et al., 2004) and their capacity has been studied in health, disease and aging (Garcia, Bailie, Martins, & Kimbell, 2007; Ho et al., 2001; Keck, Leiacker, Heinrich, Kühnemann, & Rettinger, 2000; Keck et al., 2011; Lindemann, Sannwald, & Wiesmiller, 2008; Ma et al., 2018; Naclerio et al., 2007; Naftali et al., 2005; Newsome, E, Poetker, & Garcia, 2019; Pinto & Jeswani, 2010; Wolf et al., 2004). The papers show that healthy young noses are capable of conditioning room air of different temperatures and RH up to roughly ninety percent of the needed temperature and moisture content for gas exchange (Keck et al., 2000; Keck et al., 2011; Naclerio et al., 2007; Naftali et al., 2005; Wolf et al., 2004). A commonly used parameter for the efficiency of the nasal air conditioning is the nasal mucociliary transport velocity (MTV), discussed in a following section.

TECHNICAL SPECIFICATION OF THE HUMAN NOSE

The nose is a "bi-directional, cyclic, two-part mini-device for air conditioning, air filtration unit with integrated disposal, odor sensor and infection defense". In 1939, Fritz Kahn, a German physician and painter, summarized the seven functions of the nose in a masterful and highly technical manner, Figure 1.

NOSE ANATOMY

- length: 8–10 cm, surface 150–200 cm^2
- bi-layered respiratory epithelium with cilia-bearing cells (10 million cilia per cm^2) and mucus-producing goblet cells. Specific mucins, tethered to the cilia, fill the periciliary layer (PCL). Hydration of the PCL and the covering mucus layer is precisely balanced and regulated for assuring ciliary beating and maintaining ideal viscoelasticity of mucus. The mucociliary transport velocity (MTV) varies from 0–22 mm/min, is directed towards the pharynx and propagated by beating cilia movements at a frequency of 5–20 Hz, Figure 4.
- mucus production is 1-2 liters per day (depending on filtration needs, irritation, infection, and age)
- three nasal conchae, well supplied with an adaptable blood flow, enlarge the surface, and enforce a turbulent flow profile, Figure 2.

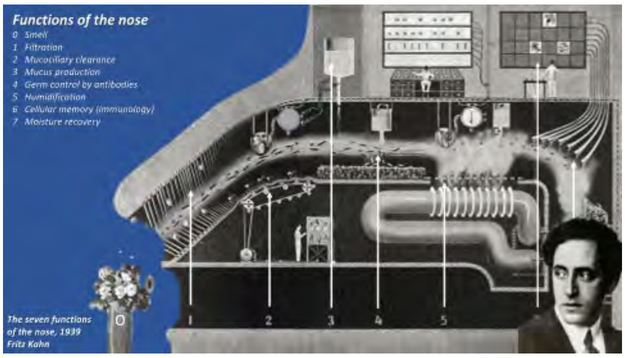


Figure 1. The seven functions of the nose, 1939, Fritz Kahn (adapted, with permission from copyright owner)

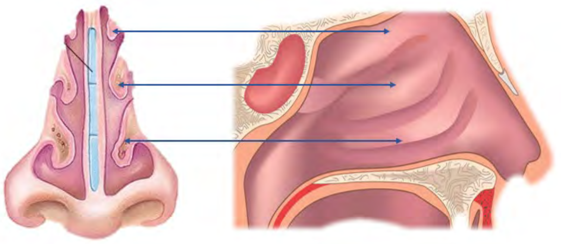


Figure 2. Cross- and longitudinal section of nasal cavity with upper-, middle and lower concha

PHYSICAL APPROACH TO AIR HUMIDITY

Humidity is the amount of water vapor or moisture in air. The amount of moisture that air may contain, depends on its temperature and pressure. Three aspects of humidity are mainly employed: relative humidity (RH), humidity ratio (HR) and absolute humidity (AH). RH is the commonly measured value that expresses the ratio of the actual water vapor to the maximal amount of water vapor that can be contained at a given temperature and pressure. RH expresses the degree of moisture saturation in percent while the difference to 100% expresses the saturation deficit, which is crucial for physiological considerations. For technical, thermodynamic calculations HR [g/kg], the weight of water vapor to the weight of dry air is mostly used, because it is independent of air temperature and pressure. AH is the weight of water vapor expressed in kilogram per cubic meter [kg/m3] or gram per liter [g/l] of ambient air and is temperature independent.

PHYSIOLOGICAL APPROACH TO AIR HUMIDITY

Completely dry air, as used in humidity ratio, does not exist in nature. Ambient air always contains at least a low amount of moisture. Therefore it is appropriate to use RH or AH for physiological considerations on humans in ambient air.

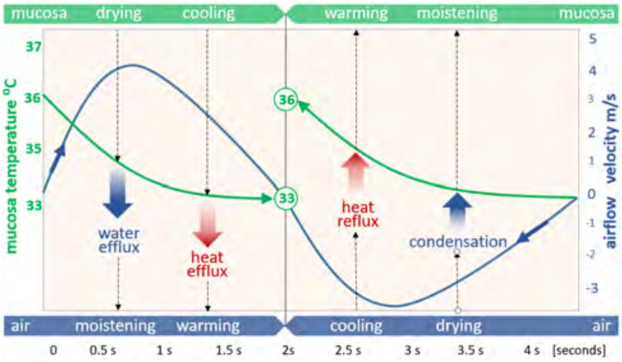
Air strives for saturation. Air is “thirsty” and therefore a sink for moisture until it is saturated. In buildings all unbound water is a potential water source for indoor air. This includes all reachable liquid water, from aerosols to the unbound water in hygroscopic animated and unanimated materials. The competition for moisture between indoor air and all reachable water sources is best described by the saturation deficit, as expressed in RH. All body surfaces of occupants, exposed to ambient air, from eyes to skin to upper airways, are part of this competition, imposed by subsaturated indoor air. Consequently, the body of literature on indoor comfort and on the impact on occupant’s surface areas employs RH for the description of heat and water exchange at the air-body interface (Wolkoff, 2018a, 2018b; Wolkoff, Azuma, & Carrer, 2021).

The correlation between indoor air and the largest surface of the human body, the air-blood interface of respiratory airways is different. The decoupling of this roughly 100 square meter gas exchange surface from indoor air conditions is essential for human survival (Williams et al., 1996). The decoupling relies on conducting airways, first and foremost on the highly specialized human nose. If nasal airways are blocked, bypassed by mouth breathing or reduced in their capacity for air conditioning, other parts of the conducting airways must overtake this vital job, even at the expense of disadvantages and complications. Since oropharynx, trachea and bronchi are far less suitable for the task of air conditioning, they easily become overstrained, dry out (McFadden, Nelson, Skowronski, & Lenner, 1999; Williams et al., 1996), cool down and the ISB shifts deeper into the bronchial tree (McFadden et al., 1999). These side effects of overstressed air conditioning, diminish the tiered infection defense of nose, oropharynx, and bronchi which depends on optimal temperature of 37°C and optimal hydration of the mucosal linings (Foxman et al., 2015; Iwasaki, Foxman, & Molony, 2017; Kudo et al., 2019; Moriyama et al., 2020).

Outer surfaces of occupants and their gas exchange surface have a divergent relationship to indoor air. For outer surfaces, the competition for water depends on the saturation deficit at ambient temperature. For gas exchange surfaces the reference temperature is core temperature (37°C) and the benchmark is saturation at core temperature (44mg/l). It is the vital task of conducting airways to add this great moisture deficit to any needed respiratory volume (Maddux, Yokley, Svoma, & Franciscus, 2016; Walker et al., 1961; Williams et al., 1996).

OPERATING MODE OF THE NOSE

In nose breathing mode, air conditioning relies to roughly ninety percent on the nose (Keck et al., 2000; Lindemann et al., 2008; Naftali et al., 2005; Wolf et al., 2004). The switch from inhalation to exhalation dictates a cycle time of roughly five seconds in tidal breathing and a bi-directional workflow that changes from heat and moisture supply in inhalation to heat and moisture recovery in exhalation, Graph 1. Along the conducting airways, down to the ISB, gradients of vapor pressure and temperature between mucosa and inhaled air change with the breathing cycle. These gradients dictate the efflux (evaporation) and reflux (condensation) of water and temperature between breathing air and mucosa (McFadden et al., 1999; Williams et al., 1996).



Graph 1. Moisture and heat balance at the air-mucus interface in a breathing cycle

Simultaneously the nose serves as self-cleaning efficient particle filter. Mucociliary clearance (MCC) is an important innate defense mechanism, essential for maintaining healthy airways (Anderson et al., 2015; Hill et al., 2014; Williams et al., 1996). The sticky mucus layer traps pathogens. Propelled by the coordinated cilia beating it removes them from the airways, thus reduces the risk of infections and the exposure to harmful airborne particles.

Proper functioning of the respiratory mucosa in nose and bronchi relies on the delicate osmotic equilibrium between mucus and PCL The water supply from connective tissue and epithelium and the net water flux from mucus to breathing air, define the parameters, Figure 3 (Anderson et al., 2015; Hill et al., 2014; Williams et al., 1996). A prominent finding of recent research on respiratory mucosa is the paramount importance of the hydration degree of mucus for its physical properties and functionality. The two key elements of host defense, mucus clearance (macro-rheology) and the penetrativeness of mucus and PCL for pathogens (micro-rheology) on their way to the epithelial cells, is optimal in a narrow range of hydration between 96 and 98 wt% (Anderson et al., 2015; Hill et al., 2014; Williams et al., 1996). Increased mucus solid content above 4 wt% by dehydration, is a fundamental biomarker for diseased mucus in chronic bronchitis and chronic obstructive pulmonary disease (COPD) with disturbed MCC (Anderson et al., 2015; Hill et al., 2014).

In exhalation roughly a third of water and heat loss during inhalation is regained (Walker et al., 1961; Wolf et al., 2004), Graphs 2. Homeostasis can be maintained as long as the net water loss is timely replaced by supply and the delicate osmotic balance between mucus layer and PCL is not disturbed (Brian Button et al., 2016; B. Button, Boucher, & University of North Carolina Virtual Lung, 2008; White, Al-Jumaily, Bartley, & Lu, 2011; Williams et al., 1996).

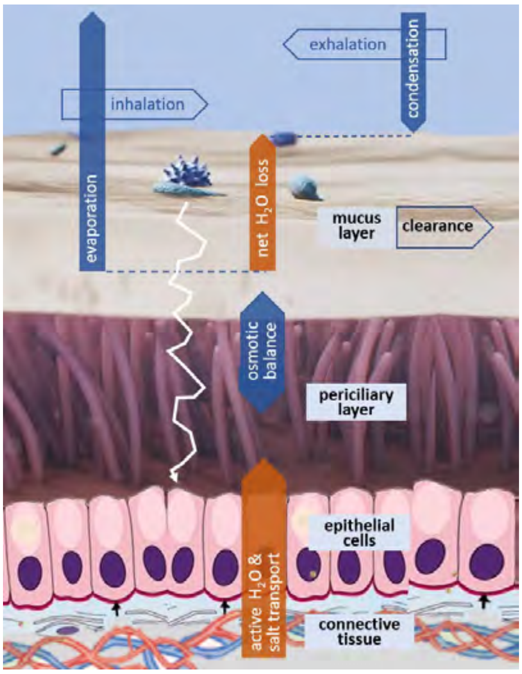


Figure 3. Balanced hydration between breathing air, mucus, periciliary layer and connective tissue. Mobility of cilia unrestricted ©Condair Group AG

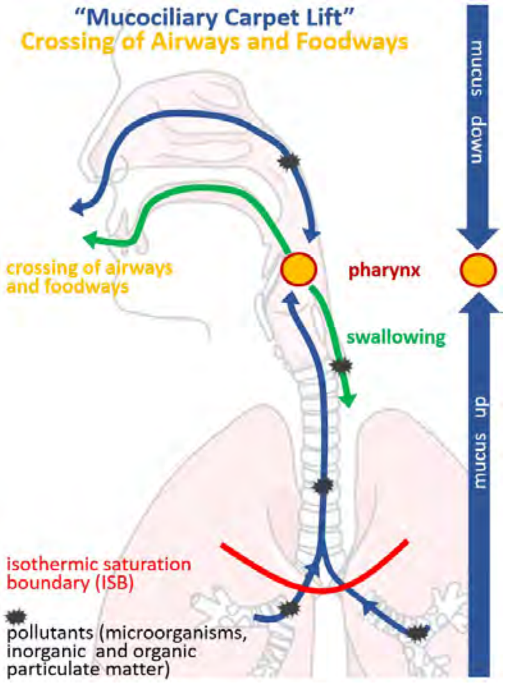


Figure 4,"Mucociliary carpet lift", crossing of airways and foodways, location of isothermic saturation boundary (ISB)

NASAL MUCOCILIARY TRANSPORT VELOCITY

The sticky mucus layer clears airborne pathogens by the "mucociliary moving carpet" that transports them to the pharynx, where they may be swallowed or coughed out, Figure 4. The mucociliary transport velocity (MTV) is the commonly used indicator for the efficiency of MCC in nose and bronchi. The two most common techniques for measuring nasal MTV in vivo are the Saccharin test and the tracking of radioactive tracers, positioned in the anterior nose. For a description of the techniques see (Deborah & Prathibha, 2014).

The controversy on whether low humidity has an impact on MTV is discussed in the paper "Mucociliary clearance is humidity dependent-contrary to common belief" in the HB2021 congress proceedings.

NOSE BREATHING

In tidal nose breathing of healthy young people the nose provides roughly 90% of total air conditioning of the upper airways (Keck et al., 2000) (Lindemann et al., 2008) (Naftali et al., 2005), Figure 5. Modelling of nasal air conditioning shows that in tidal breathing hot-dry (40°C, 5% RH) cold-dry (5°C, 5% RH) and cold-humid (5°C, 90% RH) air may be conditioned to 90% of alveolar needs (37°C and moisture saturation) by young individuals (Naftali et al., 2005).

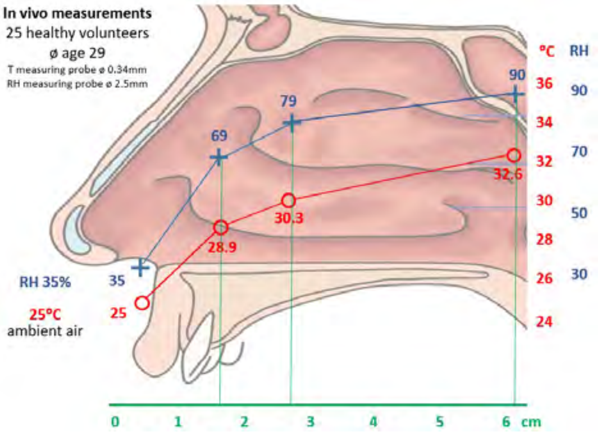


Figure 5. Humidity and temperature profile in the nasal cavity at the end of inspiration, measurements (Keck et al., 2000)

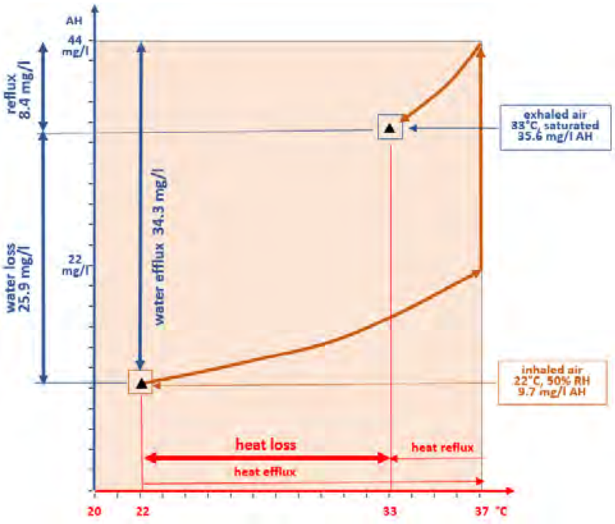
WORKFLOW AND BACKUP IN CONDUCTING AIRWAYS

When nose breathing is partially or totally blocked as it happens with any kind of rhinitis, be it infectious, allergic, age related or by imbalanced parasympathetic and sympathetic inputs (Leader & Geiger, 2021), the important contribution of the nose to air conditioning is shorted by mouth breathing. The short circuiting of the nose greatly reduces the efficiency of air conditioning shown by an increase in water loss of 42 % (Svensson, Olin, & Hellgren, 2006). The replacement of the nose cavity by the oropharyngeal cavity shifts the ISB deeper into the bronchial tree (Ingelstedt, 1956; McFadden et al., 1982; McFadden et al., 1985). From personal experience we all know, how quickly the oropharynx dries out when the nose is blocked by any reason. Whenever nose and/or oropharynx are overstressed by ambient dryness or an increased respiratory volume, the bronchial tree, as backup for air conditioning, is activated and must deliver the required air conditioning even at the expense of dehydration. Dysfunction of cilia beating, reduced MCC by dehydration, cell damage and ultimately cell death have been documented in thirteen animal studies and two human studies, summarized in a textbook on critical care medicine (Williams et al., 1996). The two human studies were (Chalon, Dolores, & Malebranche, 1972; Seo, Kim, Choi, Hong, & Hwang, 2014).

The conducting airways seem to have a high short-term back-up capacity for increased respiratory minute volumes during physical work or sports activities in combined nose and mouth breathing. How human lower airways handle the corresponding high demand for moistening, if the nose, is bypassed, is unknown. In vivo measuring of fast changing humidity in lower airways is impracticable. All existing information is derived from modeling parameters of inhaled and exhaled air and from studies with mechanically ventilated patients (Seo et al., 2014) Modelling of moisture and heat flux in moderately increased breathing rates (15/min., 0.82 l) for one minute, showed a reduction of the air-conditioning efficiency by 11% (Naftali et al., 2005). Increasing respiratory volumes and inhalation of dry air, exposes more and more of the tracheobronchial tree to incompletely conditioned air that causes dehydration and falling mucosa temperatures (Seo et al., 2014).

WATER AND HEAT FLUX BETWEEN BREATHING AIR AND MUCOSA OF CONDUCTING AIRWAYS

Water and heat flux between the mucous layer and the breathing air, are illustrated in Graph 2, adapted from (Walker et al., 1961).

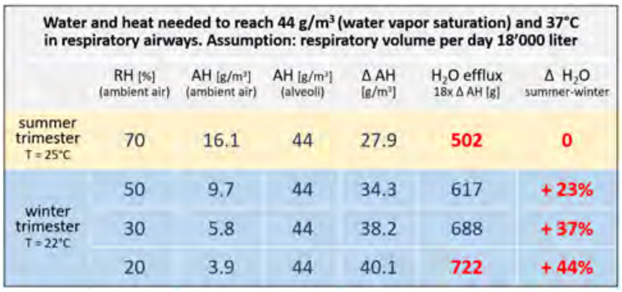


Graph 2. AH = absolute humidity, RH= relative humidity

Graph 2 illustrates a breathing cycle in ambient air of 22°C, 9.6 mg/l AH (50% RH) The heating part of air conditioning is easy to meet by our noses. Even at rest the human body represents an exothermic bioreactor that must get rid of 80 Watt to prevent overheating. The intense blood circulation in the nasal cavity provides plenty of heat transport capacity.

The challenge is high for the moistening part of air conditioning, especially in indoor air of low AH. For compensation of the evaporative water losses to dry breathing air, mucus production increases. Water efflux to breathing air and the water needed for the hydration of mucus easely exeeds two liters per day. The transepithelial transport capacity may be overstressed by the hydration demand and the mucosal lining may dessicate.

Table 1. Daily water requirement of conducting airways (namely the nose) for the conditioning of 18’000 liter breathing air in typical summer and winter indoor conditions.



Water and heat needed to reach 44 g/m³ (water vapor saturation) and 37°C in respiratory airways. Assumption: respiratory volume per day 18’000 liter

	RH [%] (ambient air)	AH [g/m³] (ambient air)	AH [g/m³] (alveoli)	Δ AH [g/m³]	H_2O efflux 18x Δ AH [g]	Δ H_2O summer-winter
summer trimester T = 25°C	70	16.1	44	27.9	502	0
winter trimester T = 22°C	50	9.7	44	34.3	617	+ 23%
	30	5.8	44	38.2	688	+ 37%
	20	3.9	44	40.1	722	+ 44%

The daily respiratory volume of an adult person is between 10’000 liters in tidal breathing and roughly 20’000 liters with working or exercising periods. For the conditioning of a daily respiratory volume of 18’000 liters the water requirement increases from 502 ml in summer (25°C, 16.1 mg/l AH, 70% RH) to 722 ml in winter (22°C, 3.9 mg/l AH, 20% RH), an increase of almost 50%, Table 1. Evolution studies show that low absolute humidity climates forced human noses to adapt in terms of increasing dimensions (nasal index, see next section). This indicates that the moistening capacity is a limiting factor for human noses in dry climates.

LESSONS FROM HUMAN EVOLUTION

Outdoor climate influenced lifestyle, look, shape and physiology of humankind throughout several million years of evolution. Our ancestors lived and worked outdoors with minimal protection from rapidly changing climate conditions. Homo sapiens became the only mammal that eventually spread across all climate zones. Evolutionary anthropology led to the recognition that three evolutionary advantages made this possible: ability of the nose to adapt to climate zones with extremely low AH, ability of the “naked ape” to avoid overheating in extremely hot climate by sweating around the body and the intellectual ability to control fire and to produce clothes and buildings (Carey & Steegmann Jr., 1981; Franciscus & Trinkaus, 1988; Tipton, Pandolf, Sawka, Werner, & Taylor, 2008; Zaidi et al., 2017). Note the impressive difference of the chimpanzee’s nose, whose habitat is tropical, compared to the human nose in Figure 6 and the large interindividual differences in nose shape.

Studies have shown that low AH in cold climate applied the strongest evolutionary pressure on human noses indicating that this is the limiting factor of nasal air conditioning (Carey & Steegmann Jr., 1981; Franciscus & Trinkaus, 1988; Maddux et al., 2016; Zaidi et al., 2017). The studies have investigated the correlation between ethnic groups living in typical climate zones and the shape of their noses. The mere fact that moistening of the ambient air exerted selective evolutionary pressure, underlines the challenging nature of this task. In fact, "one-shape-fits-all-tasks" does not work. Specific dimensions in breadth and height, expressed as "nasal index" and complex geometries are needed for optimal performance in extremely dry environments. The "living nasal index" of the respective population, measured as ratio of breadth to height, shows a significant statistical correlation to the climate zones with lowest absolute humidity, the "cold-dry" and "cold-wet", climates (Maddux et al., 2016).

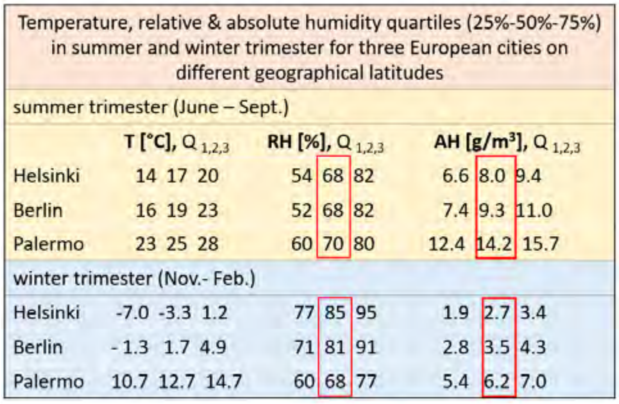
Maddux SD points out that the term "cold-wet" climate, widely used in older studies, is based on RH measurements. In fact, this climate category is less dry than the "cold-dry" but drier than the categories "hot-dry" and "hot-wet" in terms of AH. (Maddux et al., 2016; Zaidi et al., 2017) (Carey & Steegmann Jr., 1981; Franciscus & Trinkaus, 1988), all pointed to the fact that low AH is the most challenging part of climate stress on noses. They show that decreasing absolute humidity correlates best with the shift from wide and flat noses (Platyrrhine) in "hot-wet" tropical zones to narrow and prominent noses (Leptorrhine) in "cold-dry" and "cold-wet" climate. The correlation of the nasal index with temperature is less strong and even weaker with RH. In the history of human evolution, the greatest challenge and therefore the most selective pressure on our noses were imposed by "cold-dry" and "cold-wet" climates with the lowest AH's. What is the significance of these findings regarding our indoor climate in modern buildings?

Figure 6. Differences in breadth and height between humanoids and humans and in between individuals

INDOOR STRESS FACTORS "LOW RELATIVE HUMIDITY" AND "LOW ABSOLUTE HUMIDITY"

Winters in temperate climate are cold and dry. Temperatures and AH's are low, while RH is higher or at least similar to summer RH, see examples Table 2. Heating creates comfortable air temperature, has no impact on absolute humidity, but increase the saturation deficit of indoor air, reflected by low RH. This increases the dehydration stress on body surfaces including conducting airways and justifies that low relative humidity dominates the discussion on health issues in heated buildings, with focus on skin and eyes (Wolkoff, 2018a, 2018b; Wolkoff et al., 2021). For the conducting airways, especially the nose, this is less than half of the challenge. For vital reasons they need to add the whole moisture difference between AH of room air and saturated breathing air at core temperature. Otherwise the dryness susceptible gas exchange would shut down (Williams et al., 1996).

Table 2. AH in winter trimester is less than half of AH in summer trimester in temperate climate.



Temperature, relative & absolute humidity quartiles (25%-50%-75%) in summer and winter trimester for three European cities on different geographical latitudes									
summer trimester (June – Sept.)									
	T [°C], $Q_{1,2,3}$			**RH [%], $Q_{1,2,3}$**			**AH [g/m³], $Q_{1,2,3}$**		
Helsinki	14	17	20	54	68	82	6.6	8.0	9.4
Berlin	16	19	23	52	68	82	7.4	9.3	11.0
Palermo	23	25	28	60	70	80	12.4	14.2	15.7
winter trimester (Nov.- Feb.)									
Helsinki	-7.0	-3.3	1.2	77	85	95	1.9	2.7	3.4
Berlin	- 1.3	1.7	4.9	71	81	91	2.8	3.5	4.3
Palermo	10.7	12.7	14.7	60	68	77	5.4	6.2	7.0

Contrary to heating, ventilation has an impact on any moisture input by humans, human activities or by unbound water in reservoirs or hygroscopic materials of buildings. Depending on the air change rate, ventilation, especially not demand controlled mechanical ventilation, extracts indoor moisture that exceeds outdoor levels.

Although indoor comfort climate is a hot topic, datasets including indoor temperature and relative humidity (absolute humidity may be calculated) covering a whole winter season, are scarce. Measurements in forty residential apartments in New York (Quinn & Shaman, 2017) and in six high-quality commercial buildings in the Midwest (Reynolds et al., 2001), showed median indoor AH of 2.7 to 4.9 g/m^3 and indoor RH of 12 to 24% in winter trimester.

The industrial revolutions forced most people to an indoor lifestyle. They are exposed to an indoor climate that a majority perceives as comfortable. However, for the conducting airways, especially the most challenged noses, indoor climate in winter is more stressful than almost all outdoor climates in terms of AH. The measured AH's in the study of Quinn (Quinn & Shaman, 2017) were all lower than the mean AH in the two most stressful climates, studied by Maddux SD (Maddux et al., 2016). The annual means of AH in “cold-dry” climates were 6 g/m^3, in “cold-wet” climates 7,5 g/m^3. At room temperature 22°C, RH’s below 40% are at the same level or below the above-mentioned annual means of stressful outdoor climates.

CONSEQUENCES OF OVERBURDENED CONDUCTING AIRWAYS

The persistently high humidification need for breathing air in low indoor AH in winter, overburdens all noses with suboptimal moistening capacity as described before (Elad, Wolf, & Keck, 2008; Ewert, 1965; Lindemann et al., 2008; Naclerio et al., 2007; Naftali et al., 2005; Salah, Dinh Xuan, Fouilladieu, Lockhart, & Regnard, 1988; Sun, Hsieh, Tsai, Ho, & Kao, 2002; Sunwoo, Chou, Takeshita, Murakami, & Tochihara, 2006; Wolf et al., 2004). As mucus membranes of the nasal cavities dry out and nasal MCC slows down, mouth, oropharynx, trachea, and bronchi must take over the task of air conditioning, although being far worse equipped for this challenge.

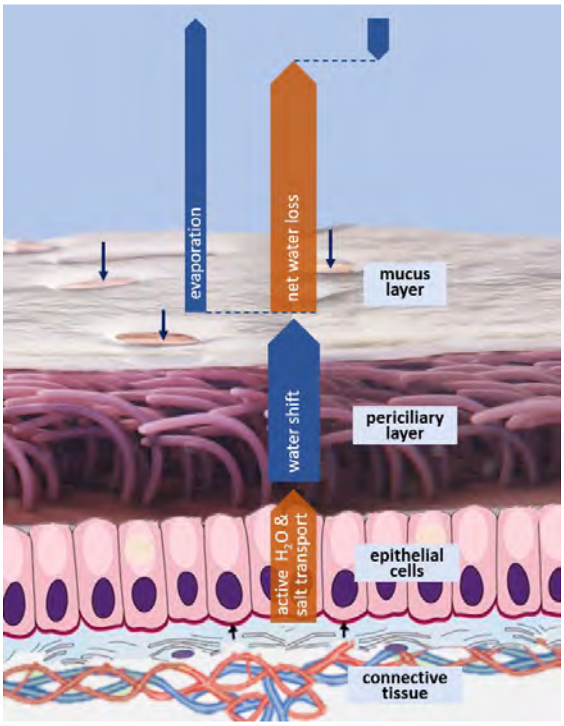


Figure 7. If the net water loss of mucus layer is higher than the maximal water transport capacity from connective tissue, volume depletion of PCL immobilizes pressed down cilia.

Underperforming nasal air conditioning may initiate a cascade of deteriorating mucosal performance that pushes the ISB deeper into the conducting airways (Williams et al., 1996, McFadden 1999). Increasing respiratory minute volumes further expand the mismatch between demand and supply of moisture to the inhaled air. If evaporation from the mucus layer to the inhaled air exceeds the supply capacity of water transport from blood via epithelium and PCL, the delicate osmotic balance mucus - PCL gets disturbed. The osmotic water-drawing power of mucus exceeds that of the PCL. The resulting water loss and volume shrinking of the PCL, depresses the cilia and may finally stop their motion (Anderson et al., 2015; Brian Button et al., 2016; Hill et al., 2014), Figure 7.

The mucus layers of the nose and bronchi act like a “moving carpet lift”. All airborne pathogens, from air pollution to microbes, that stick to its surface, are carried towards the larynx. Here they are swallowed or coughed out together with a mix of mucus and saliva, Figure 4. This creates a time frame for penetration via mucus and PCL to the epithelial cells that depends on MTV and the entrapment site. In well hydrated mucosa of upper airways, the time frame is between less than one minute up to a maximum of thirty minutes. Considering the multiple obstacles on their way to the epithelial cells (micro- and nano-porous meshwork of mucins, IgA, enzymes, toxins, pH-gradients, electromagnetic and hydrophobic-hydrophilic interactions), the time window is tough (Lai, Wang, Wirtz, & Hanes, 2009; Zanin, Baviskar, Webster, & Webby, 2016). If mucus membranes are well hydrated, pathogens frequently lose the race against time.

Low outdoor AH in winter of temperate climates triggers an indoor climate that favors airborne transmission of respiratory viruses and decreases the infection defense of human airways (Moriyama et al., 2020). Winter epidemics of respiratory infections are linked to low outdoor and indoor AH (Arundel et al., 1986; Lubart, 1962; Ritzel, 1966; Sale, 1972; Wolkoff, 2018a; Wolkoff et al., 2021). Five intervention studies have shown the positive effect of humidification in winter by reducing respiratory infections and absenteeism (Ritzel, 1966; Sale, 1972), Gelperin A (1973) and Green GH (1974, 1985). The last two authors are referenced in (Arundel et al., 1986). Although known for more than half a century, the link is still not commonly recognized.

CONCLUSION

Winter indoor dryness in terms of low absolute humidity over stresses an increasing percentage of our aging population. With the currently available scarce datasets on indoor dryness, the impact on winter epidemics of respiratory infections is difficult to prove. We need widespread, large datasets including temperature, RH, calculated AH and CO_2 from diverse building designs and housing technologies. Matching them with spatially and temporally resolved epidemiological data on seasonal respiratory infections would give us the much-needed consolidated database.

The intervention studies that focused on the above question were conducted decades ago and the claim for maintaining medium RH of 40 to 60%, corresponding to AH of 8 to 11.5 g/m^3 in the comfort temperature zone, has been raised for decades. The author takes the view that the above requested datasets and new intervention studies will enhance the claim that maintaining 40 to 60% RH in our buildings would have a preventive effect against winter epidemics.

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