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INDOOR RELATIVE HUMIDITY: RELEVANCE FOR HEALTH, COMFORT, AND CHOICE OF VENTILATION SYSTEM

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ABSTRACT

It is generally recommended to keep the values of relative humidity (RH) indoors between 40 and 60% for comfort and health. However, the environment in our homes and offices is a lot dryer in the winter, going down to 20% or less in cold climates. We can be in such dry environments for short periods, but in the long term we might get physiological impairments such as dry or irritated eyes, nose, throat and skin, and even an increase on headaches and respiratory or skin diseases and allergies. On the other hand, too high values of relative humidity can promote growth of fungi and mites, and create moisture problems in building materials. Those problems could be solved by finding a balance between ventilation rate and indoor humidity production, in combination with moisture absorbing materials. However, these strategies work better with lower air speed and ventilation rate, which may in turn conflict with the need for fresh air to compensate for the production of CO2 and other pollutants. Typically, mechanically ventilated spaces tend to have a lower RH than those with natural ventilation, independently of the season and indoor temperature, since their main focus is providing enough fresh air to keep CO2 levels below 1000ppm. Recently, it has gained acceptance to monitor temperature, humidity and CO2 for indoor air quality and health, which has the potential to show their interactions and help find an optimal balance between them. We carried a building performance simulation (BPS)analysis of an office building with an optimized design for passive strategies and automation in cold climate. Instead of focusing on high air changes, this building uses extra high floors for stratification of temperature and pollutants, to reduce the need for ventilation in winter. Then we compared indoor RH under natural and mechanical ventilation, to reflect on the effect of the ventilation system.

KEYWORDS

Relative humidity; thermal comfort; indoor air quality; building performance simulation.

1. INTRODUCTION

The indoor environment in our homes and offices tends to be too dry in the cold and intermediate seasons. With a relative humidity as low as 20% or even less, we may experience dry or irritated skin, eyes, nose and throat, more frequent headaches or even respiratory or skin diseases and allergies (Wolkoff 2018). That happens because when we warm up the incoming air from a colder environment, it gets dryer. Its water content does not change, but its relative humidity decreases since the air can contain more humidity as it gets warmer. In cold climates, the warmer indoor air can host up to 10 times more humidity than the colder outdoor air. This means that as we ventilate a room, we are actually removing water vapour from it. So, the room air gets dryer unless we balance the ventilation rate with the production of humidity indoors (occupants, plants, cooking, bathing), use moisture absorbing materials that help buffering the changes in relative humidity, and/or lower the temperature (Woloszyn et al. 2009).

We can be in such dry environments for short periods, but if prolonged in time, we might get certain physiological impairments, especially in our skin, eyes, nose and throat, with dryness and irritation, more frequent headaches or even respiratory or skin diseases and allergies. Therefore, it is generally recommended to keep the values of relative humidity indoors between 40 and 60% for comfort and health. (Arundel et al. 1986)

With a relative humidity of less than 40%, we become more vulnerable to viral respiratory infections, because of the drying of our mucous membranes. In addition, low humidity levels activate the evaporation of water in cough droplets, so that they shrink and get a prolonged suspension in the air and ability to travel faster and longer thanks to their smaller size. (Ahlawat, Wiedensohler, and Mishra 2020)

On the other hand, too high levels of humidity can promote growth of fungi and mites, and create moisture problems in building materials (mould, decay, condensation, corrosion), which in turn can also affect your health. (Baughman and Arens 1996)

Keeping optimal indoor humidity levels in the winter might be challenging because of our competing demands for thermal comfort and air quality. As indoor air gets polluted over time by the users (CO_2, odours) and by the materials inside our buildings (emissions, odours), we need to ventilate the rooms to get more fresh air. On the other hand, new research about comfortable conditions and air quality in commercial aircrafts suggest that the current limits for CO_2 concentration used in buildings may be overestimated (Giaconia, Orioli, and Di Gangi 2013). The current maximum levels of 1000-1200ppm have been calculated as a function of the acceptable outdoor CO2 concentration (350 to 500ppm) and ventilation rates of 7.5 L/s per person. Relatively high values of CO_2 concentration are not toxic “per se”, but they are usually correlated to stuffy air and odours from bio-effluents. Following new findings, the limit of carbon dioxide in workplaces may be safely set to 2000ppm for comfort and 5000ppm for safety (EuropeanStandard 2009).

In addition, we have gotten used to warmer indoor temperatures in our buildings, which in turn produce lower air moisture levels.

However, the biggest challenge when attempting to assess the impact of too dry environments on us is that we do not have dedicated moisture sensors in our bodies (Pfluger et al. 2013). As we cannot directly perceive water vapour, the perception of “dry air” can occur as a side effect of increasing temperature, pollution (CO_2, odours) or dust levels, which makes it difficult to isolate and measure.

In addition, we are much more sensitive to the effect of *respiratory cooling*, where the nose acts as a regenerative heat and moisture exchanger (Pfluger et al. 2013). This means that the air we breathe in is effectively helping us to cool down by convection and evaporation inside the nose. Therefore, lower temperature and humidity levels will create a pleasant, cool and “fresh” sensation, despite constant “pollution” of the air. In contrast, higher temperatures and relative humidity can give an impression of “stuffy” air (Fang, Clausen, and Fanger 1998).

Besides, the moisture absorption/desorption by the materials is a *very slow process* that may take up to one year or more, which makes it more complex to simulate and test.

Since relative humidity is inversely related to temperature, a very easy way to improve the environment in a building could be to *lower the indoor temperature*. If you keep it down to 21°C instead of 25°C, you can obtain a 10% increase in the moisture level, which can significantly help improving comfort and health.

However, the combined need to balance out ventilation against moisture production and allow enough time for the building materials to react with ambient humidity, might still make it necessary to lower *air speed* and *ventilation rate* inside the building. That is why mechanically ventilated spaces tend to provide a dryer environment than those with natural ventilation, independently of the season and indoor temperature (Alsmo and Alsmo 2016). Mechanical systems generally focus on higher ventilation rates to give a sensation of "fresh air" and compensate for pollutants production. In the past, they tried to humidify the incoming air to get a moister environment, but this created sometimes problems with bacterial growth (legionella) inside the conditioning equipment.

More recently, it has gained more acceptance to monitor both *temperature, humidity* and CO_2 in office buildings, to improve indoor air quality perception and fight/reduce sick building syndrome (SBS) (Redlich, Sparer, and Cullen 1997). This can allow us to see more clearly their interactions and find a better balance between their competing strategies.

In order to better appreciate the correlation between ventilation rate, relative humidity and CO_2 concentration, we have carried out a building performance simulation (BPS) analysis of an office building with two different ventilation solutions, but with similar temperature curves. In this way, we tried to limit the variables of the systems so that we could appreciate the changes in relative humidity and CO2 concentration, depending mainly on the ventilation rate.

2. METHODS

The *case* analysed in this study is Baumschlager-Eberle 22/26, an *office building* in Lustenau (Austria) with automated natural ventilation, instead of a conventional mechanical ventilation system. It was chosen because of being a rather *extreme example of passive design optimization for cold climate* resulting in very stable indoor conditions throughout the year. The most interesting quality of the indoor environment in this building is actually the near-optimal range for relative humidity, which is within 35-60% even in the cold and intermediate seasons (Hugentobler et al. 2016). These values are in contrast with the much lower humidity levels (down to 10-30%) that are so common in energy efficient buildings, for similar outdoor conditions (Frei, Reichmuth, and Huber 2004; FGK 2015).

Within the building, we focused on the *second floor*, where the local office for the architectural firm Baumschlager-Eberle is located. Being an intermediate floor, it is not affected by border conditions just below the roof or right above the ground, limiting its interaction with the outdoor climate just through the façade. Then, we chose the office on the *north-west corner* because of being the most critical orientation for the cold season, with least amount of solar radiation during working hours.

The energy concept of the building is referred to as *"Concept 22/26"* (Eberle, Aicher, and Hueber 2016). Its objective is to keep the room temperatures throughout the year between 22 and 26°C, to keep a comfortable indoor environment while minimising the use of resources (materials, space, energy). In order to do so, the building envelope must have a very low heat transfer and a high thermal capacity. Moreover, the mechanical HVAC system has been replaced here by a *building automation system* that operates window opening for natural ventilation (fresh air and cooling), and lighting system for backup heating. Indoor temperature, relative humidity and CO_2 concentration are measured by sensors in every office, to ensure user comfort and energy efficiency (Junghans and Widerin 2017).

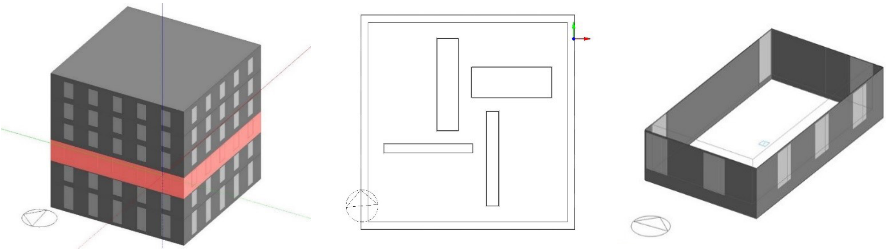

Figure 1. We modelled the whole building in DesignBuilder but focused on the North-west office on the second floor, for the simulations. Images from DesignBuilder

The extensive use of passive strategies include:

- compact shape, as a cube of around 24 x 24 x 24 m^3, to minimize heat loss
- exposed thermal mass indoors, to flatten temperature fluctuations
- high levels of insulation (average wall U-value=0.138)
- very airtight envelope (n50=0.51 on blower door test)
- window-to-wall ratio around 20%
- near-floor-height windows, for good daylight distribution
- triple glazing (U-value=0.7, SHGC-value=0.55)
- narrow vertical vents (VIP) by each window, for natural ventilation (cooling / fresh air)
- window position by inner surface of external walls, for shading
- high ceilings (3.4m) to allow for temperature and CO_2 stratification, thus limiting the need for natural ventilation in the heating season

The high-performance building envelope allows the use of the *internal gains* to cover most of the heating demand in the cold seasons. The automated natural ventilation is then limited to providing fresh air to meet indoor air quality requirements. A downside of having natural ventilation directly from the façade is the reduction in the occupancy density. In order to protect the users from draft, they have to seat at a distance from the windows. In this case, this is resolved by placing the circulation by the façade, instead of by the core.

Then the lighting system functions also as backup heating, which is possible thanks to the high-performance envelope, that minimizes heating needs. Yet, it had to be resolved with low efficiency luminaries (fluorescent tubes), in order to provide enough heat. This use of the lighting system as a backup heating is needed mainly in the heating season, when very low temperatures are expected in the early hours of the working day. Even though this could be considered as some sort of electric heating, it has the

wall	U-value (W/m2 K)	0.138
	Internal heat capacity (KJ/m2 K)	85.76
	Infiltration rate (ac/h)	0.037
window	U-value (W/m2 K)	0.7
	Solar transmittance factor (SHGC)	0.55

Table 1. Main characteristics of the building envelope (Junghans and Widerin 2017)

advantage of using an already existing system for two different functions (lighting and heating), instead of installing two different systems. The equipment considered for the internal gains corresponds to one computer and two screens per user.

We used Meteonorm (Remund 2008) to create the *typical meteorological year* (TMY) weather file for the BPS analysis in Lustenau, by interpolation from the nearest weather stations (latitude 47.25°N, longitude 9.39°E, altitude 405m). This file was obtained as the average from 10 years of temperature measurements (2000-2009) and 20 years of solar radiation (1991-2010).

With a mean temperature of the warmest month 19.6°C and 0.6°C for the coldest, it corresponds to a Köppen climate type *Cfb* (temperate, with warm summer and no dry season). Also, with 2980 HDD18 and 1277 CDD10, it gives an ASHRAE type *4A* (mixed and humid). In this temperate (borderline with cold) climate, only 8.6% of the hours fall inside the comfort zone, prior the application of any passive strategies for climate adaptation.

Next, we performed the *BPS analysis* of the building in EnergyPlus with DesignBuilder as graphical user interface (GUI). These tools were chosen because of their capability for simulating the behaviour of thermal mass and moisture

Occupancy density (people/m2)	0.05
Equipment (W/m2)	11.50
Lighting (W/m2)	5.0

Table 2. Internal gains (Junghans and Widerin 2017)

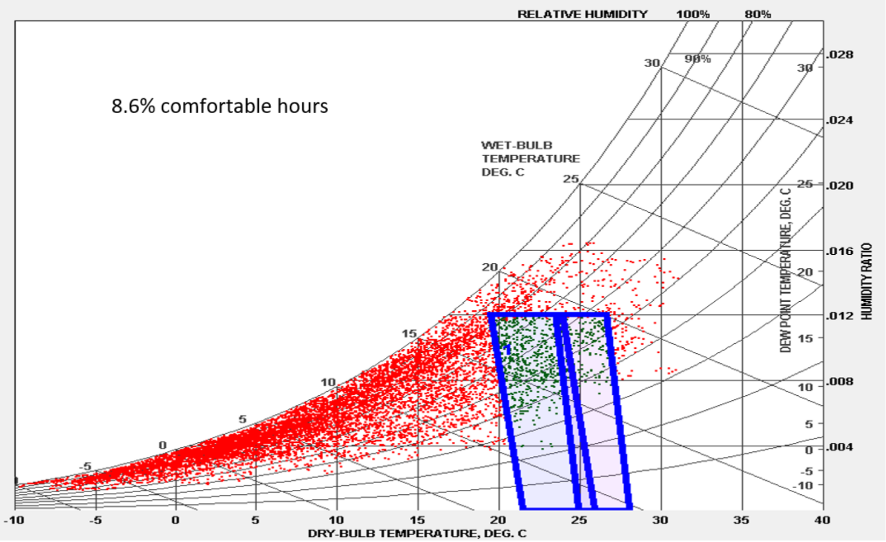

Figure 2. Psychrometric chart for the outdoor climate in Lustenau, Voralberg, Austria

buffering of the materials in use, as well as the possibility for extensive tailoring in the operation of building components and systems with EMS coding (energy management systems). (Crawley et al. 2001; Ellis, Torcellini, and Crawley 2008)

We considered *two cases* in our simulations, one with natural ventilation and one with mechanical ventilation, where we included a whole year warm up period with internal gains, to allow the full thermal and moisture load of the materials. Then, the moisture buffering properties of the different construction elements were introduced, so that we could use the EMPD (effective moisture penetration depth) calculation method for heat and mass transfer. This was necessary in order to produce a more accurate approximation to the indoor relative humidity. We chose the EMPD method over the more detailed HAMT, because it produces very close results to those from HAMT but with much shorter simulation time and fewer errors (Woods, Winkler, and Christensen 2013).

For the case with *natural ventilation*, we designed the vents to resemble the original ones in BE2226 as much as possible (narrow VIP panels on north side of each window, along their whole height, with an opening of 45° to the outside). These vents are controlled by the EMS to maintain optimal values of indoor air temperature and CO_2 concentration. Then, the lighting system responds to the need for adequate light levels (500 lux) in the occupied hours, acting as well as backup heating if needed (but off during the night, in consideration to the neighbours). This system is also controlled by EMS coding.

For the *mechanical ventilation*, we used a heating, ventilation and air conditioning system (HVAC) with heat recovery and without setback schedule (always on). We used the HVAC settings for best practice in Austria (DesignBuilder) with default horizontal vents auto created under the windows, to allow enough air circulation in such an airtight building. In reality, this could have been solved more neatly by having a balanced ventilation system, but this option was not available in the software. Also, it is common practice to introduce a setback schedule for the unoccupied hours, but then we obtained higher indoor temperatures, so we opted for keeping the system always on to obtain a temperature curve as similar as possible to the one from the natural ventilation case, for comparability.

3. RESULTS & DISCUSSION

As mentioned earlier, we wanted to study the results from the natural ventilation and automated controls, in contrast with a comparable HVAC system (similar thermal behaviour but higher ventilation rate).

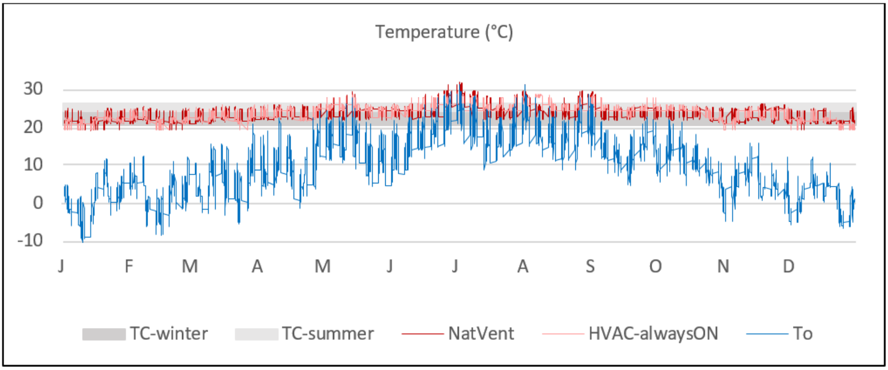

Figure 3. Annual air temperature comparison between automated natural ventilation and HVAC system

We tried to match the temperature curves from the two systems, so that we could see more clearly the effect of the ventilation rate on the relative humidity and CO_2 concentration. The automated natural ventilation allowed for a somewhat higher variability and was not so capable to control the summer peaks. At the same time, this system was also providing slightly higher winter temperatures. Still, they pose a reasonable match, given how different the two systems are, both in principle and operation.

We allowed for a whole year warm up period with internal gains (bi-annual simulation run period). Compared to the conventional annual simulation, only the relative humidity with natural ventilation offered a significant difference, for the first months before the summer. When compared with the relative humidity from the HVAC system, we can appreciate an important increase in the winter months, getting much closer to the recommended 40%. In the summer months, we get slightly more stable values with natural ventilation, though both systems give similar curves. It seems like the lower ventilation rate of the automated natural ventilation allows the moisture buffering properties of the materials to soften the curve and increase the average values for the relative humidity. In contrast, the HVAC system provides a better indoor air quality with respect to CO_2 concentration, keeping it within the optimal range. The natural ventilation system, by prioritising a low ventilation rate that activates the moisture buffering of the materials, allows the CO_2 concentration in the winter to raise to the higher limits of what is acceptable, yet it does not allow it to increase over 1200 ppm. In the summer, on the other hand, the levels of CO_2 are even lower with natural ventilation, though both of them produce values far below the limits.

In the graphical comparison between the two systems, it becomes apparent the difference in ventilation rates, where the HVAC system usually produces more than double the air changes per hour even in the summer.

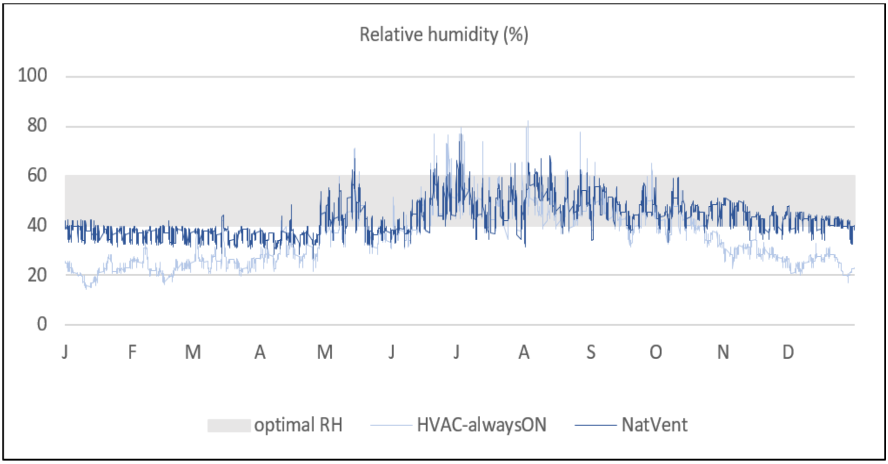

Figure 4. Relative humidity comparison from the two systems under study

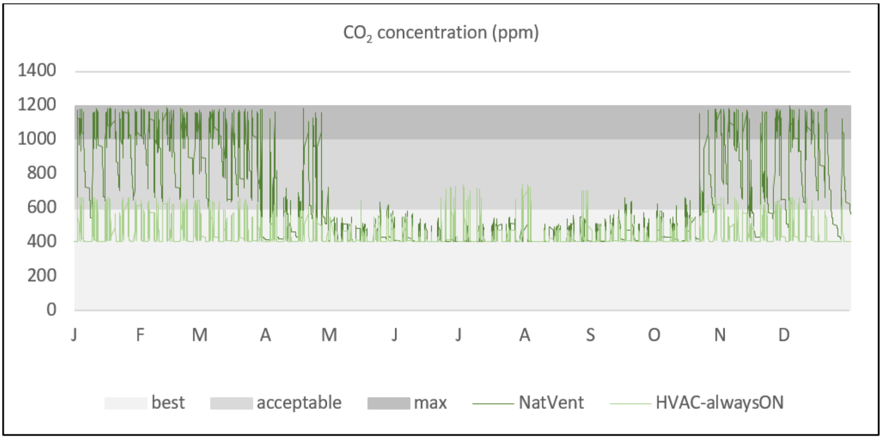

Figure 5. Air CO_2 concentration comparison for the natural and mechanical ventilation systems

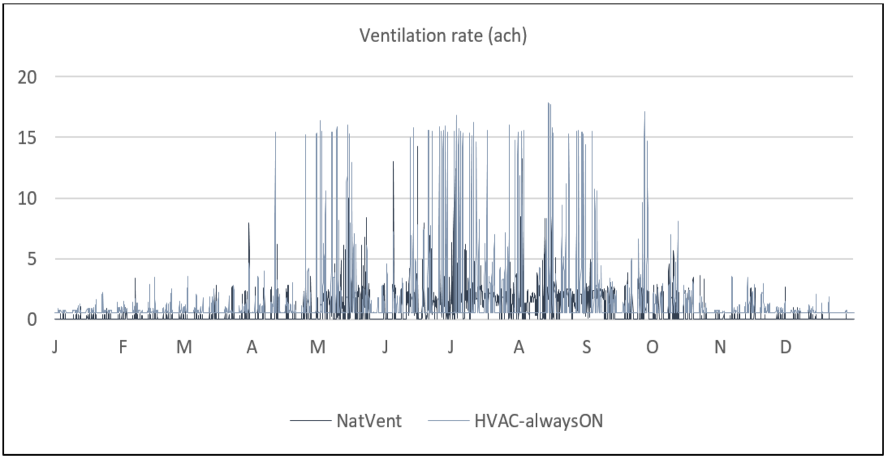

Figure 6. Comparison between ventilation rates for the natural and mechanical ventilation

Even though the annual curves for the air temperature are a reasonably close match, the differences in relative humidity result in a very different indoor climate for the natural ventilation and the HVAC system. While the first is mainly grouped between 30% and 60% relative humidity curves, most of the latter spreads between 15% and 55%. Still, they both have a very high number of hours inside the comfort zones for winter (left) and summer (right), though slightly higher for the natural ventilation (89h vs. 84h).

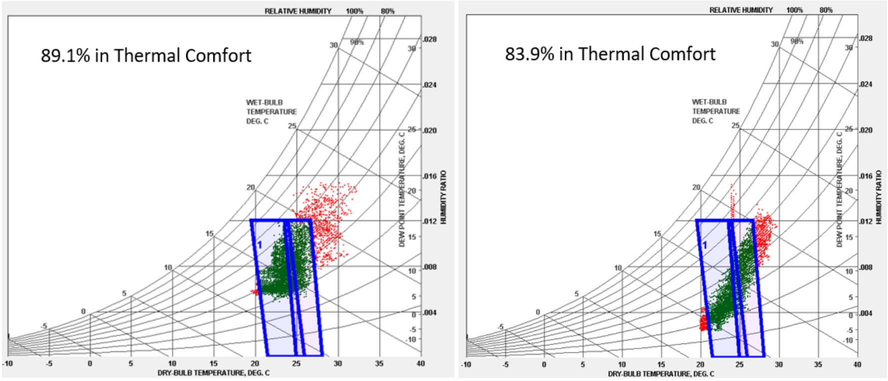

Figure 7. Psychrometric charts with the indoor climates created by the two systems. To the left is the natural ventilation, and the HVAC to the right. (Climate Consultant)

We can observe some overheating in the summer months, occurring for both systems, but more significant for the natural ventilation. This could be greatly reduced by adding solar shading to the windows, not present in the original building.

This paper studies the effect that the choice of ventilation system can have on the indoor relative humidity (RH) and CO_2 concentration. The aim was to provide similar thermal behaviour with different ventilation rates, so that the resulting RH and CO_2 could be compared. Then again, HVAC systems are rather complex and could be fine-tuned to provide a similar environment to that from the automated natural ventilation. The question in this exercise was not whether to use natural or mechanical ventilation, but to become aware of the need to adjust the ventilation rates to achieve a better balance between our competing needs for RH and CO_2. Traditionally, the main objective was to achieve low CO_2 concentrations, even at the expense of creating too dry environments. Nowadays though, we know more about the possible adverse effects of too low RH for our health in the long term (Pfluger et al. 2013), so we ought to consider both parameters when designing the ventilation system of our choice.

4. CONCLUSIONS

As a general recommendation, we should try to keep air humidity levels within the *optimal values of 40-60%* for human health in indoor spaces. This can be best achieved by balancing ventilation rate with moisture production, combined with moisture absorbing materials and lower indoor air temperature. An important step for finding this balance while ensuring a good indoor air quality is to monitor both RH, temperature and CO_2 concentration, so that we can adjust the ventilation rates according to our needs.

A revision of the current limits for CO_2 concentration indoors to include the latest findings from the research community would be of great help for finding a more reasonable balance between the competing interests for CO_2 and RH, for indoor air quality, health and comfort.

Then, further research is needed in order to update the Building Bioclimatic Chart and thermal comfort standards to include more reasonable limits of RH for health and comfort.

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