Humidification in healthcare facilities - knowledge base and practice

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Abstract. Humidification is not a common procedure in many buildings in the Netherlands. An exception are buildings used for healthcare, especially hospitals. There, e.g. in operating theatres, relative humidity (RH) generally is controlled stringently at levels around 50%. From an energy point-of-view humidification is an energy-intensive activity. Currently, more than 10% of the total energy used in healthcare buildings is spent on humidification. The basis for an RH of around 50%, however, is not clear. Therefore, we pursued a scoping review to find evidence for specific RH thresholds in such facilities. In addition, an inventory was made of the current practice in the Netherlands. After analyzing the title and abstracts, the remaining references were read by two persons and scored on several topics. Guidelines and current practice were analyzed by referring to existing (inter)national guidelines and standards, and by contacting experts from Dutch hospitals through a survey and semi-structured interviews. Outcomes from the literature review were grouped into four different topics: 1) micro-organisms and viruses, 2) medical devices, 3) human physiology and 4) perception. No scientific evidence was found for the currently generally applied RH set-point of ~50%. Some studies suggest a minimum RH of 30% but the evidence is weak, with exception of medical devices if specifications require it. A lack of research that addresses more long-term exposure (a couple of days) and includes frail subjects, is noted. It was found that RH requirements are strictly followed in all hospitals consulted, some only focusing on the hot zones, but in many cases extended to the whole hospital. Steam humidification is mostly applied for hygienic reasons. but is quite energy-intensive. The conclusion t is that there is no solid evidence to support the RH-setpoints as currently applied in the Netherlands. It merely appears a code of practice. Therefore, there appears room for quick and significant energy savings, and CO2 emission reductions, when considering control at lower RH values or refraining from humidification at all, while still fulfilling the indoor environment requirements and not negatively influencing the health risk. This outcome can be applied directly in current practice with the available techniques.

Keywords. Relative humidity, Health, Energy, Hospitals, Literature review, Guidelines, Survey.
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1. Introduction

Also in healthcare sustainability is an issue of concern. In order to align with the need to reduce CO_2-emission, a so-called Green Deal Duurzame Zorg [1] (Sustainable Care) has been initiated by the Dutch government. Healthcare facilities are an important energy consumer and effort is put in reducing the energy demand of such type of facilities. The energy demand, amongst others, relates to the conditioning of the indoor environment. Temperature, relative humidity and air quality are examples of indoor environment parameters which are controlled to support the healthcare process. From literature, we know that the indoor environment affects health, well-being, comfort and productivity [2–4]. The conditions that are set for the parameters that constitute the indoor environment, determine the energy demand in the end. Efficient solutions for realizing these conditions support the reduction of the energy demand. Alternatively, relaxing the requirements (conditions) concerning the indoor environment may also help in reducing the demand, or support the energy flexibility [5]. However, energy savings in healthcare cannot be realized at the expense of the primary process, i.e., availability of functions, patient safety, quality of care and the preconditions within which this care must be provided. In other words, the quality of the healthcare and the performance of the building to support that process cannot be compromised.

Nevertheless, we see that assumptions for indoor environment requirements are not that rigorous. Guidelines for health-based criteria exist when dealing with indoor air quality [6,7]. However, for many contaminants information is still lacking.

Focusing on relative humidity (RH), if values are provided, they generally refer to (thermal) comfort. For healthcare, when related to RH, in the Netherlands current practice heavily relies on past assumptions and codes of practice, e.g. from the former Dutch College Bouw Zorginstellingen [8]. As a result, in the Netherlands, RH in healthcare environments is generally controlled at around 50%. Due to the climatic conditions, then air humidification is required, which therefore is a standard component of the air treatment in HVAC systems for healthcare facilities, particularly in hospitals, but also in long-term care. Nevertheless, the scientific evidence for this code of practice is meager. Notably, air humidification, applying central steam humification, is an energy-intensive process. As a result, humidification is a relatively large energy consumption item (>10%) [9].

Following the above, we see two directions for addressing the sustainability requirement in healthcare settings, related to the RH. First, there is a need to derive more (scientific) evidence for the code of practice as applied currently, that assumes RH values in a relatively small range around 50%. Secondly, current practice with respect to RH-settings and air humidification can provide further insights into how humidification in the Netherlands, in healthcare facilities, is dealt with and what options are available as an alternative.

In view of the situation outlined above and the two clearly different subjects which relate RH to sustainability, this research has been divided into two parts. On the one hand, a literature study was conducted into what limits for relative humidity conditions are in place for the indoor environment, specifically in healthcare settings, in order to achieve a safe environment for patients and staff from the point of view of health and comfort. On the other hand, using current practice as a starting point, an inventory was made to summarize RH set-points and humidification solutions, as currently applied within Dutch hospitals, and assess possibilities (techniques) that could be considered for realising humidification safely and sustainably. This has been translated into two research questions:

1. What is the necessity of humidification, i.e., which RH condition is required in care facilities from the point of view of safety and comfort of the patient and the nursing staff and is there a distinction in functions?

2. In which alternative, more energy-friendly way, can humidification be realised? This taking into account patient safety and comfort requirements of the building users.

2. Methods

2.1 Scoping review (knowledge base)

In order to answer the first research question, a literature study (so-called scoping review) was conducted. The scoping review included studies till November 2020, with a specific supplement on electrostatic discharge till February 2021. It consisted of five different steps: 1. identify the research question, 2. identify relevant studies, 3. select studies, 4. identify themes, 5. report. The steps are based on the framework of Arksey and O'Malley [10] and assume an iterative process. The iterative process makes it possible to go back to earlier steps if new insights are gained that can give more direction to the next step in the review process.

The literature study focused on the necessity of humidification in healthcare buildings from the point of view of patient and staff safety and comfort, and process support. For that, the literature study focused on the following four topics:

1. The effect of RH concerning the survival of micro-organisms and viruses;
2. The effect of RH on the functioning of medical equipment;
3. The effect of RH on human physiology;
4. The effect of RH on perceived human well-being and comfort.

The included databases for the scoping review were: Scopus, Pubmed, Web of Science and Science Direct. The choice was made to search databases from a health perspective and a building perspective so that the theme of air humidification in healthcare buildings was mapped as broadly as possible. The search terms applied were based on the categories indoor air quality, environment, perception, experience and comfort and micro-organisms and viruses.

Fig. 1. Flow diagram screening process publications.

The screening process and its outcome are summarized in **Fig. 1**. After processing the results from the search on duplications and the first screening on title and abstract, in total 78 publications were read completely and assessed by two team members. The assessment was performed based on an assessment matrix (rubric) covering topics such as reliability, context, method, usefulness of the results and conclusion. The assessment resulted in a score. The maximum score that could be arrived at was 27. Inclusion or exclusion of an article was discussed if opinions for a publication differed by 5 points or more between the reviewers, or if the score was around 10-20. In general, only articles with a score higher than 15 were included. In the end, a total of 46 publications were included after the screening process.

In the analysis of the information from the articles, the effect of RH on the four topics indicated above was treated separately.

2.2 Practice (inventory)

In the second part of the study, an inventory was made of the current practice, with regard to humidification in Dutch hospitals. This information was obtained through semi-structured interviews with relevant experts in The Netherlands, selected from the research network (e.g., facility management staff and clinical physicists), employed by hospitals and manufacturers of medical equipment. The interview was designed to discuss issues related to (i) requirements set for the relative humidity, (ii) whether requirements differ between functions in the hospital, and (iii) what humidification principles are used for humidification. In total experts from 20 different hospitals were consulted in this way.

In addition, desk research was applied to gather information on standards and guidelines and with respect to techniques applied for humidification, apart from steam humidification.

The concept reports from both studies were presented to a group of experts and persons from practice for peer-review and content validity. These were experts in different fields such as medical specialists (pulmonologist, medical microbiologist), doctors, infection prevention specialist, and technical related experts such as a building services engineer and facility manager. In combination with a rebuttal document to answer the remarks made, their comments were implemented in the final version of the report.

3. Results and discussion

3.1 Knowledge base

The outcomes of the literature study have been gathered in tables that provide information on the type of study performed (e.g., Experiment, Intervention, Case study, Literature study), the environment in which the research was performed (e.g., Hospital, Office, School), and a summary of the specifics of the outcome. A full overview of the tables as developed can be found in [11]. An example of a part of one of the tables developed is shown in **Fig. 2**. Below we summarize the main findings from the literature review and the subsequent analysis.

The information obtained has been grouped according to the four topics indicated: 1) Micro-organisms and viruses, 2) Medical equipment, 3) Physiological aspects and 4) Perception of comfort and well-being. The included studies indicate that RH is often not investigated as a separate parameter but in combination with various other aspects. It, therefore, is not always straightforward to quantify the individual effect of the RH on the outcome.

From the point of view of microbiological organisms, there is a dependency on the type of organism. Temperature and RH conditions outside the host determine the chance/time that for example, a virus, can remain infectious. However, the conditions under which the chance of survival is greatest differ per organism and it is not possible to state a specific value for this. In general, low and high RH values should be avoided. Studies regarding the relationship between RH and transmission of micro-organisms and viruses have not been found.

The lower RH limit used for medical equipment is associated with electrostatic discharge (ESD). To limit ESD, a lower limit of 30% RH is found for medical equipment. The specifications of such equipment are leading for the minimum RH value to be applied, because this can influence the functioning of the equipment. From a comfort point of view, it is also desirable to prevent ESD (shocks when touching surfaces and other people) by using the right material, e.g., footwear (conductive) and bedding (cotton). The RH can reduce this form of ESD, but it cannot completely prevent it.

Subthema / Thema	MAX. 27 Score	Omgeving	Type Studie	Micro organismen				
				Schimmels	Bacteriën	Virussen	Mijten	Allergenen
[Dabisch et al., 2021]	24	AC	EXP			RV 20%-70% [T=10-30°C] inactivitatie SARS-CoV-2 nauwelijks beïnvloed.		
(Wolkoff, 2018)	23	KO	LS			RV > 40% Virus ↓		
(Shajahan et al., 2019b)	22	ZO	LS	RV > 45%-50% bevordert schimmelgroei	RV > 45%-50% beinvloedt concentratie bacterieen	T=30°C bij een RV 50% om griepvirussen te beheersen		RV > 45%-50% beinvloedt concentraties allergenen
(Božić, Ilić, & Ilić, 2019)	21	ZO	CS	→ RV 30% - 40% *	→ RV 30% - 40% *			
(Heutte et al., 2017)	21	ZO	EXP	RV kan worden beschouwd als omge-vingsdeterminant van schimmels in de lucht.				
(Pyankov, Bodnev, Pyankova, & Agranovski, 2018)	21	LO	EXP			Overleving neemt af bij hete en droge lucht *		
(Mousavi et al., 2019)Iran	21	ZO	CS	RV 23% - 33% *	coagulase-negative staphylococci (68%), Micrococcus, bacillus RV 23% - 33% *			
(Yang, Elankumaran, & Marr, 2012)	20		LO			Influenza virus en de levensvatbaarheid; RV <50% ↑*		
(Lowen & Steel, 2014)	19,5	ONB	EXP			Transmissie tussen gastheren ~100% bij T=5°C en RV 20% -35%		
(Peccia, Werth, Miller, & Hernandez, 2001)	19,5	AC	EXP		Afname inactivatie bij gebruik UV-C bij RV>50%; Natuurlijke inactivatie wordt niet beïnvloed door RV in range 20%-90% *			

Fig. 2. Example of a part of the table as prepared from the literature review. The example shown is for micro organisms and viruses. Note that the information in the example is in Dutch.

RH values	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Micro-organisms											
Medical equipment											
Physiological aspects		5-30%									
Perception and well-being											

Fig. 3. Summary outcome literature study for the four identified topics investigated. The gradient in colour indicates that there is no fixed value. The orange colour indicates that there is room for lower RH-levels to be applied. An upper RH-limit could not be identified.

Physiological symptoms such as dry eyes, nose complaints, respiratory complaints and headaches can be caused by low RH levels. Many complaints related to physiological symptoms seem to increase at RH lower than 30%. The studies considered, however, often have the limitation that the duration of exposure to these conditions is not explicitly given or is limited (up to a few hours). More long-term exposure (a few days, e.g., related to patient hospitalization) has not been investigated, while this will be the case for the most critical persons (patients) within the care facility. The results available generally are more representative of an outpatient situation. For that matter, there are almost no studies available that address optimal RH-conditions for personnel in such facilities.

In general, significant effects of RH on the perception of dry air seem to be limited. Individual sensitivity may have an effect on this perception. With respect to thermal comfort, the sensitivity to RH, when in normal ranges, is low [12].

Fig. 3 summarises the outcomes of the literature review. It again distinguishes the four topics that were investigated in the context of healthcare buildings. We conclude from the literature available that strict guidelines on RH for healthcare facilities are not to be derived from the current (scientific) information as available in literature. From the overall results, a minimum level of 30% RH may be suggested, but the evidence is weak. In **Fig. 3** the orange colour indicates that there is room for lower RH-levels. We do not propose a higher limit for RH as no information is available to support such a limit for a healthcare environment. Specifications for medical equipment, however, may require such a limit. With respect to air humidification, the lower limit is of most interest, though in practice of course higher RH levels remain possible due to climatic conditions.

The outcome deviates somewhat from reviews such as that from [13]. Sterling et al. propose a RH range between 40% and 60%, at normal room temperatures. The focus of that review is mainly on micro-organisms and a few physiological outcomes and did not focus on healthcare environments. The current review is wider and focuses on healthcare environments.

The concept of dry air in relation to perception and physiological outcomes is complex, as Wolkoff [14] concludes. The closely related link between low RH and indoor air pollution is an underlying explanation for that. In line with the conclusion from Wolkoff, we also find that current research with respect to the effect of RH on physiological and perceived outcomes is missing. Especially research that resembles realistic situations, in space and time. In this respect there also is an urgent need to distinguish between the 'average' person and the average type of person that is expected to frequent healthcare more often, i.e., frail and aging people.

Following the information gathered from the literature review, there currently is no actual scientific support to keep the RH-level in Dutch hospitals at the generally applied 50% RH. Put otherwise, there is no information available in the current scientific literature that indicates that a RH-level of 50% is best for the people working and staying in healthcare environments. A lower value would still provide for a similar performance on the separately identified topics.

3.2 Practice

Inventory Dutch hospitals

From the inventory, it is concluded that 100% of the surveyed Dutch hospitals (n = 20) apply air humidification as part of their HVAC system for conditioning the supplied air. 72% of the respondents indicated that they use steam humidification as a source for that. The remainder (28%) uses a combination of steam and water humidification. Water humidification alone or combined with steam humidification generally is restricted to low-risk rooms, such as offices. For high-risk rooms, such as operating theatres, steam humidification is applied in all cases because of hygienic assumptions. This is generally done centrally. Decentralized solutions are only applied due to in-use changes of function or rooms. The majority of the hospitals (83%) apply humidification for the entire building. The set-points that are applied vary per hospital surveyed and depend, amongst other things, on the chosen grouping of functions. In 89% of the cases the users of the building are not able to change the RH set-point. That is done centrally by the facility management.

Almost all respondents indicated a subdivision for the operating theatre (hot-zone) and the category 'miscellaneous' which can be considered the remaining functions. Some respondents distinguished these other function groupings with different climatological requirements (e.g., office function, patient room, ICU/CCU, laboratories, pharmacy, lung department, scope department and MRI room). The majority of the set-points used in practice for the operating theatre were ≥50% RH. For the other rooms this was 42.5% RH, with a wider spread in outliers due to the many different function groupings in this category (see **Fig. 4**). According to the respondents, the reason for using strict RH requirements is based on the requirements for medical equipment, comfort, hygiene and perception of wound dehydration, and from guidelines, history and experience.

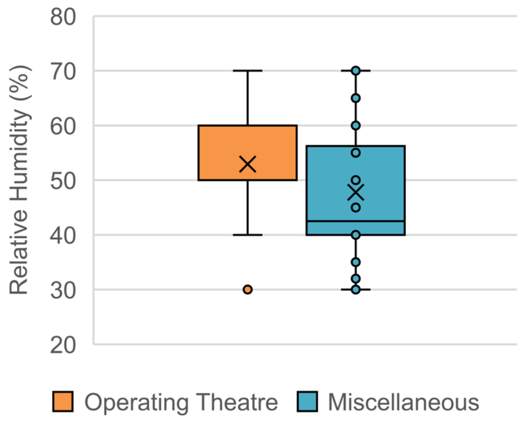

Fig. 4. Distribution of RH set-points as applied currently in practice in the Netherlands.

The inventory of (inter)national standards and guidelines results in an overview of the current recommendations for air humidification. This overview is summarized in tables and can be found in [15]. Standards and guidelines do not show unanimity with respect to the required RH conditions in healthcare settings, and do not provide a scientific knowledge base for suggested RH requirements. An RH of 20% is the lowest lower limit found [16], while a lower limit of 50% RH is used in publications of the former Dutch College Bouw en Ziekenhuisvoorzieningen [8].

Alternatives to (steam) humidification

As could be concluded from the survey, steam humidification is currently the most common technique in Dutch hospitals, when humidification is applied. By heating water (>100°C), steam is produced and supplied to an air stream. The advantage of this technique is the very likely elimination of pathogens.

An alternative to steam humidification is water humidification (i.e., adiabatic humidification). With water humidification, water in its liquid state is supplied into the air flow (i.e., spraying, vaporizing or atomizing) so that no heating of the water is required before addition. However, evaporation of moisture in the air removes heat from the air stream, causing it to cool and requiring additional energy to bring the air flow up to the required temperature before being supplied into a room.

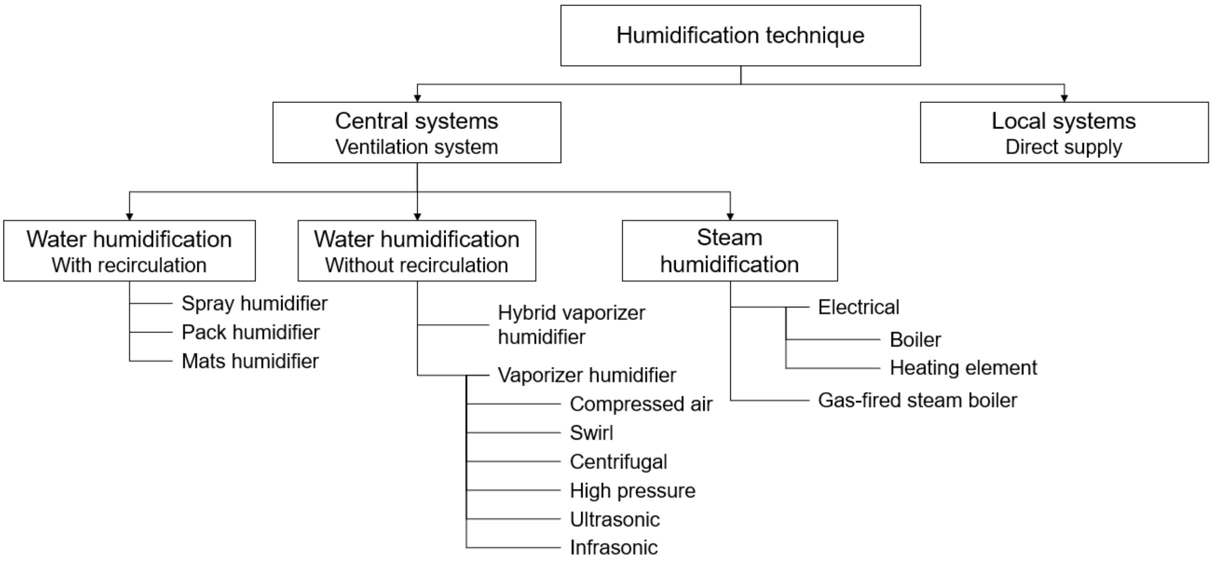

Fig. 5. Overview of available air humidification techniques.

Different types of humidification techniques can be applied when using water humidification. **Fig. 5** provides an overview of the techniques currently available. Techniques with and without recirculation are available. Water humidification with recirculation uses collected water to minimize water consumption. In any case, the microbiological safety, e.g., because of legionella, of this form of humidification still needs to be monitored, in order to gain sufficient certainty about the functioning and safety of such systems in healthcare applications.

Standards and guidelines reflect this precaution by preferring steam humidification over water humidification. Some standards, e.g. DIN194604 [17] only allow the use of steam humification in operating theatres. In the case of water humification, additional requirements are prescribed to assure hygienic performance.

The advantage of water humidification is found in the possibility to apply renewable forms of energy, in combination with a heat pump, to condition the supply air. This is nearly not possible for steam humidification, due to the high temperatures required for that process. On the other hand, hydrogen gas and electricity can be applied to produce steam. Steam production generally is done centrally and therefore prone to heat losses in the distribution process.

4. Conclusion

This study has shown that, in practice, strict requirements are often set for the relative humidity, while the justification for these strict requirements cannot be found in the scientific literature, or is only very limited available or very weak. In general, research on this specific subject, related to healthcare environments, is scarce. This also limits the possibility of providing a good quantitative foundation for the values to be set for the RH in such environments. Based on the available information, an indicative lower limit of 30% RH may be desirable, considering issues such as medical equipment, physiological aspects and well-being and comfort. For micro-organisms and viruses, no general relationship has been found between the occurrence and inactivation of these and the RH. For that matter, more aspects than humidity alone play a role in the transmission and development of infections. An upper limit for RH cannot be advised, as there is no unambiguous optimum for all four topics described in the knowledge base. The emphasis of the studies found and analyzed is on low values for RH. In the context of humidification, the lower limit is of most interest.

In addition to the fact that information on the effect of RH on the identified topics is limited, the connection with the healthcare environment is even more limited. It is concluded that the available research is not well aligned with the situation as found in a healthcare setting. That mainly relates to the duration of the studies performed, generally in the order of hours, and to the subjects involved, healthy (young) people. That is not representative for an in-house patient that is required to stay for a few days in a patient room. There is an urgent need to have research outcomes available that reflect this actual situation better.

Per room or function, primarily a balance will have to be found between presence of (medical) equipment, presence of patients and perception of comfort, with regard to humidity on the one hand and the resulting energy consumption for humidification on the other hand. If there are rooms where medical equipment is used that is sensitive to humidity (high/low RH-values), such as MRI and CT scanners, or other critical equipment, specific requirements can be leading. While in other situations, where no critical equipment or critical processes take place, the need for humidification can be questioned, based on the knowledge base gathered in this research.

5. Acknowledgement

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6. Data access statement

The datasets generated and analyzed during the current study are not publically available because of privacy reasons, but they will be available on request and in consultation. The information from the literature review is available through the refered report.

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