INDOOR AIR IN LONG TERM CARE FACILITIES AND SPREAD OF INFECTIOUS DISEASES

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SUMMARY

Not much is known about the favourable indoor air conditions in long term care facilities (ltcf’s), where older adults suffering from dementia live. Due to the decrease in cognition function, it is hard to evaluate comfort and health in this group. Nevertheless, infectious diseases are a persistent problem. Based on literature an assessment method has been developed to analyse ltcf’s to determine if differences in building characteristics and HVAC systems influence the spread of airborne infectious diseases. The developed method is applied in seven long term care facilities in the Netherlands. From this research it can be concluded that this method has potential to evaluate and compare ltcf’s and develop design guidelines for these buildings. However, some adjustments to the methodology are necessary to achieve this objective. Therefore the relation between the indoor environment and infection risk is not yet analysed, but a consistent procedure to analyse this link is provided.

INTRODUCTION

The number of older adults is increasing rapidly in European societies. Aging goes together with sensory changes and an increased risk of age related diseases like dementia (van Hoof et al, 2010). Frail older adults suffering from dementia often need institutional care and therefore live in ltcf’s. Since the physical environment directly influences health and wellbeing, careful attention to the indoor environment in ltcf’s is desirable. However, there are no special requirements for ltcf’s (Kort, 2012). Indoor environmental standards are based on the perception of average people whereas older adults, especially those suffering from dementia, are known to have a different sensitivity of the physical environment (i.a. Anderson, 2011; Bae, 2009; Norbäck 2009). Little is known about the current indoor climate in these ltcf’s, although the effect of the physical environment on the health and wellbeing of patients has proved to be important (Huisman, 2012). According to Aminoff (2007) poor indoor environmental conditions may have a role in the suffering of people with dementia. By adjusting the indoor environment to the needs of the residents, it is expected they put less demand on the professionals working in the ltcf’s.

Apart from the fact that a poor indoor air quality can cause health problems, air can also transfer pathogens of airborne diseases. The study of Li et al (2007) emphasized the need for investigating the impact of indoor air environments on the spread of airborne infectious
diseases, as little known about the impact of airflow patterns on infectious disease propagation. The transmission of infections is complex, and controlling the infections at the psycho geriatric (PG) departments of LTCF’s is hard because:

- Residents live close together and can freely interact (Siegel et al., 2007).
- Advanced age goes together with a declining immune system and a weakened host defence that makes it more likely for infectious agents to invade (Chohan et al., 2001).
- Illness is often recognized after it has already spread, because of subtle presentation of the infection, the lack of onsite diagnostic facilities and the presence of co-morbid illness, which obscure the symptoms of the infection. Delays in diagnosing and treating infections increase the risk of transmission within the facility (Garibaldi, 1999).
- It is hard to apply restrictions for residents because they do not understand the situation (Siegel et al., 2007).

There is not much evidence that ventilation reduces the risk of transmission of infections. But there are studies that suggest that an insufficient amount of ventilation contributes to the spread of airborne diseases, but no minimum ventilation rate is known (WHO, 2009). The reason for this little evidence is first of all due to the large number of factors that can contribute to the transmission of the infections and the fact that the (airborne) evidence of the airborne infection rapidly disappears once the infection period is over. Finally the influence of the ventilation impact is often too difficult to be quantified (Li et al., 2007). Beggs (2003) concluded that the contribution of the airborne route is likely to be greater than expected, though contact spread is the principle route of most infections.

Airborne transmissions occur when organisms are contained in droplet nuclei or in dust particles containing microbes. The droplets with respiratory infections can spread during activities such as talking, coughing and sneezing (Xie et al., 2009). For a prolonged period of time they remain suspended in the air and can spread widely (Brankston et al., 2007). The size of these droplets mainly determines the time they remain airborne, have the possibility to spread infectious diseases and thus, determine the strategies for controlling the respiratory droplets generated during the expiratory activities (Xie et al., 2009). Although not much quantitative data is available, a laboratory study of Noti et al. (2013) concluded that maintaining indoor relative humidity at 40%, will significantly reduce the infectivity of aerosolized virus. Analyses of the macro-environmental level show that: a high airflow rate, air distribution pattern that has a high ventilation effectiveness and personalized ventilation may reduce the risk of cross infection. Additionally, apart from airborne transmission, the indoor air quality may also play another role in the infection by weakening the defence mechanism of individuals. A poor indoor air environment can negatively influence the healing process, recovery and wellbeing (Norbäck, 2009).

It can be concluded that the relation of the indoor air and its effect on the outbreaks of infections with health and comfort, as illustrated in figure 1, is hard to quantify. The objective of this research is to provide a method to analyse current long term care facilities to see if differences in building characteristics, HVAC systems and indoor air influence the spread of airborne infectious diseases. It should assist in the development of design guidelines for the indoor environment in LTCF’s.

**METHODOLOGIES**

Because little is known about the current situation of indoor air in LTCF’s and it is difficult to describe favourable conditions, a methodology has been set up to study the contribution of
indoor air to the spread of airborne diseases. This methodology is based on the Health Optimisation Protocol for Energy-efficient Buildings (HOPE) study (2002). The HOPE study investigated if energy-efficient buildings can also be healthy buildings and was performed in office buildings. This current study will focus on the relation between indoor air and the outbreaks and spread of airborne infectious diseases in LTCFs.

Development evaluation methodology
The structure of the methodology is illustrated in figure 1. The methodology consists of a systematic evaluation of building and indoor air related variables that might contribute to the spread of infections. A literature study has been carried out and used to define these variables. For each, it has been specified whether it contributes to the airborne-, contact route or both. These are all divided in different categories for evaluation:

- Building characteristics: a building checklist has been composed, based on the HOPE checklist, to evaluate building and location related variables.
- HVAC system characteristics: the same has been done for the variables of the HVAC systems. This checklist also includes airflow measurements.
- Use of the building: an interview has been set up with a team manager of the PG department in which the use of the building is discussed. This semi structured interview contains the following topics: general, residential groups, activities, control over the indoor climate, hygiene and outbreak of diseases.
- Indoor air parameters: a measurement protocol has been set up to measure the indoor air parameters which are assumed to be related with the spread of airborne diseases. This includes temperature, relative humidity, CO₂ and particulate matter measurements.

In comparing the history of outbreaks of infections in LTCFs, a list of parameters is set up to describe these outbreaks from the past 3 years. The type of infection, the date an outbreak started, the period of infection, the number of infected persons (residents and professionals) and the locations within the building are included. Additionally a questionnaire about health and comfort, also in analogy with the HOPE study, has been set up for health care professionals, since the indoor air also influence comfort and health of building users.

Data collection
The methodology was tested by applying it in seven PG departments of long-term care facilities in the Netherlands. A requirement for the buildings is that the building is at least three years old, so data about the outbreak of infections can be compared. The evaluation at the location can be carried out in one day. Indoor air measurements were placed for a time span of 40 days. Unfortunately these measurements were only carried out at two locations due to the availability of measurement equipment. A time period of two weeks was given, for filling out the questionnaires.
Data analyses

The data has been analysed in four steps. First an overview was made of the results of all buildings together to give more insight in the current building quality. Then the investigated buildings were ranked from the point of view of infection prevention. After that the different buildings are compared and finally it is described how correlation between variables can be determined.

1. Overview results all buildings

A method has been set up to give an overview of the results of the building evaluation of all buildings. First the level of measurement of all variables has been determined. From the ratio and interval data, boxplots are made as shown in figure 2a. The minimum and the maximum of this boxplot are defined from the data from the investigated buildings. Boxplots are displayed horizontally. The minimum value is defined as the least favourable condition (at the left), and the maximum value as the most favourable condition (at the right). This is done from the point of view of preventing the spread of airborne infectious diseases. From the variables with an ordinal measurement level, boxplots are made as well and shown in figure 2b. The minimum and the maximum of these boxplots are defined from the range of possible answers (multiple choice). The minimum value is the least favourable condition, and the maximum value is the most favourable condition. Horizontal bars, figure 2c, are used to show the results of the binominal and nominal data. The bars represent the percentage of the investigated buildings for which this answer is applicable. If the answer of the question is not known for a location, because the information was unavailable or not applicable, the graph was calculated from the results of the remaining buildings. The number of buildings that are included in this total answer is indicated at the right of the graph. The use of the buildings has been analysed by comparing the written interviews. Similarities and differences are discussed for each of the categories. The data of the questionnaires of all locations have been put together, so health care facilities that had a larger number of respondents have a greater contribution to the total result. A data template has been used to process the data.

A) Example ratio and interval data: What is the average space (m$^3$) per resident?
From the obtained data, the following values can be calculated and a boxplot can be made.

<table>
<thead>
<tr>
<th>Min</th>
<th>Q1</th>
<th>Median</th>
<th>Q3</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>78</td>
<td>87.0</td>
<td>95.0</td>
<td>114.7</td>
<td>130.0</td>
</tr>
</tbody>
</table>

B) Example ordinal data: How are different residential groups separated?
1 = Corridor open; 2 = Corridor with closed doors; 3 = Corridor open and different floor levels; 4 = Corridor closed and different floor levels; 5 = Different floor levels; 6 = Different buildings
From the obtained data, the following values can be calculated and a boxplot can be made.

<table>
<thead>
<tr>
<th>Min</th>
<th>Q1</th>
<th>Median</th>
<th>Q3</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
<td>3.5</td>
<td>5</td>
</tr>
</tbody>
</table>

C) Nominal data: What type of control system is there for the mechanical ventilation?

<table>
<thead>
<tr>
<th>Type of control mechanical ventilation</th>
<th>1 Central - manual</th>
<th>2 Central - clock</th>
<th>3 Central - demand</th>
<th>4 Local - manual</th>
<th>5 Local - clock</th>
<th>6 Local - demand</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
</tr>
</tbody>
</table>

Figure 2. Examples boxplots and graph to give an overview of the results.
2. **Ranking buildings**

For each building, the results of the evaluation are compared with all investigated buildings. The result of a variable for a building is indicated with a horizontal bar in the boxplot. The bar indicates whether the score of that building, is in the 1st, 2nd, 3rd or 4th quadrant of the boxplot. A score is assigned based on the quadrant the answer is in, figure 3. This score indicates how well the building scores compared to the other investigated buildings. Answers that are in the 1st quadrant are part of the 25% least scoring buildings and receive a score of 4. Answers that are in the 4th quadrant are part of the 25% best answers and get a score of 1, figure 3. The score does not imply that a building with a score of “1” is in any case good and a score of “4” is bad. Due to the lack of guidelines and references no optimum can be defined. The ranking is used to find the effect of differences between buildings and its effect on health and comfort.

<table>
<thead>
<tr>
<th>Score</th>
<th>1st quadrant</th>
<th>2nd quadrant</th>
<th>3rd quadrant</th>
<th>4th quadrant</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Least 25%</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Best 25%</td>
<td>4</td>
<td>3</td>
<td>2</td>
</tr>
</tbody>
</table>

Example: What is the average space (m³) per resident? Answer building X: 125 m³/pp.

Within 4th quadrant so a score of 1 is assigned to this building for this variable (right side of graph)

![Figure 3. Schedule and an example of assigning scores to the buildings.](image)

3. **Comparing buildings**

Radar plots are used to give an overview of the scores of one building. Figure 4 shows an example of the radar chart. The chart is divided in three parts, as indicated in the figure.

![Figure. 4 Example of a radar chart](image)

The first part of the radar is composed using the building and HVAC related variables and consists of six axes: 1. General building characteristics, 2. Contaminant source control, 3. Building materials, 4. Ventilation, 5. Maintenance and air cleaning, 6. Temperature & humidity. Each axis consists of different variables that influence the parameter. The average of the variables is used to calculate the score of the axis. Because the contribution of each of these variables is unknown, no weighting factors have been applied. If one of the variables is unknown, the average of the other variables is used to determine the score. The percentage of answered questions is indicated for each axis. When this percentage is lower than 75%, the value “0” will be assigned. A score of 5 indicates that the parameter does not meet the requirements of the building legislation. The second part of the radar indicates the scores of three parameters referring to the outbreaks of infections. Health and comfort scores are shown...
in the third part. The chart should give a quick insight in the aspects for which a building has a good or bad scores and helps to find possible correlations between the three categories.

4. Correlations

Using the radar chart of each building, possible relations can be found and further analysed. By sorting the buildings, for example, on the frequency of infections, patterns in the building and HVAC characteristics might be observed. These possible relations can then be further analysed depending on the data. The same can of course be done for other parameters. In order to check whether desired conditions also have a positive influence on health and comfort of health care professionals this relation should be analysed as well. Two charts as outcome of the developed assessment methodology of the seven investigated ltcf’s are shown as an example (figure 5).

![Radar chart for two of the investigated ltcf’s.](image)

DISCUSSION

The aim of this study was to develop a method to analyse ltcf’s to investigate how differences in building characteristics, HVAC systems and the use of the building influence the spread of airborne infectious diseases. Application of this method on existing ltcf’s provided an overview of its applicability and the expected outcome for existing ltcf’s. Both are discussed in more detail below.

To apply the developed method, assistance is necessary from different persons to obtain information that is not frequently used. Experience has shown that a change in facility management is necessary to make the technical information better accessible and comparable. Health care facilities in the Netherlands are obligated to report notifiable infections and symptoms because of their potential infectiousness (GGD, 2012). However there is no uniform structure on how this information is stored and for how long. The rules can be interpreted in various ways, differs in the level of completeness and therefore is hard to compare. A more systematically way of data collection of outbreaks is necessary to rank and score the buildings. The parameters on the axes of the radar chart consist of different variables. However, the impact of each of these variables is not yet known. In the current analyses the different variables are divided in categories in which their contribution is assumed to be the same. More research is needed to find out whether weighting factors or a hierarchy should be applied in this analysis. The Delphi method (Okoli and Pawlowski, 2004) or the analytic hierarchy process (AHP) (Saaty, 1990) are techniques that may be applied for that. Nominal variables cannot be incorporated in the radar chart. So for example air movement and the contribution of natural ventilation, which are important according to the literature study, are not included in the scores. These variables need a higher level of measurement. So variables need to be quantified or divided in sequential categories. Looking at the contribution of the
indoor air quality on the transmission of infections by weakening the defence mechanism of individuals, it is unfortunate that the perceived health of the residents is not evaluated. Methods that could be applied, like an observational study or an interview with health care professionals about their experience with the residents, are time consuming.

Currently the building evaluation is mostly descriptive based. More indoor air measurements are needed to support the validation of the model. Quality requirements can be added to the descriptive variables to ensure comparability. Currently, only maintenance, the year the building was built and renovations take the quality of the systems (for a small part) into account. The Design Research Methodology (DRM) can be used to structure the development of the model to fulfil its purpose. DRM as described by Blessing (2004) divides the research design in four stages, which is illustrated in figure 6. The model as currently designed has past the first two stages. Though, it should be noticed that iterations can still take place. Stage 3 starts with the provided model and the additional information for further development. The methodologies suggested in this paper can be used to systematically develop the model. This can then be evaluated by expending the sample size of the participating ltcf’s. Apart from evaluating the assessment methodology, the increased sample size can be used to define criteria for the outbreaks of infectious diseases and health & comfort perception. If the model is validated, relations between on one hand the building characteristics and HVAC systems, and the other hand the spread of infectious diseases and health and comfort of health care professionals can be analysed. When more information is available about the desired conditions and the effect of the building and HVAC characteristics, criteria for the buildings can be integrated in the model as well. Then ltcf’s can use the model to structure the buildings and HVAC characteristics and define their positions compared to other ltcf’s. The model shows the strengths and weaknesses and provides insight in aspects that need attention.

![Figure 6. DRM framework (Blessing, 2004)](image)

Since the type of information required for the analysis is now scattered across many different people, in its current form application of the model already has shown to provide the respective stakeholders of ltcf’s with a much improved insight of the functioning of their building with respect to its indoor air quality. The model gives information about the ranking of one building compared to other investigated buildings, it shows strength and weaknesses of a building and it shows the effect of the building and HVAC characteristics on infections and the perceived health and comfort. Nevertheless, it is recommended to carry out improvements as discussed to make the method better applicable and thereby serve as a tool to find correlations, determine design guidelines and assist facility managers to improve the building quality of ltcf’s.

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