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Limiting the spread of long-range airborne diseases in Long Term Care Facilities

J.M.A de Kort [a], *M.G.L.C. Loomans* [b], *L. Havinga* [c]

[a] Faculty of Architecture, Building and Planning, Eindhoven University of Technology, Eindhoven, the Netherlands, j.m.a.d.kort@student.tue.nl; j.m.a.d.kort@gmail.com

[b] Faculty of Architecture, Building and Planning, Eindhoven University of Technology, Eindhoven, the Netherlands, m.g.l.c.loomans@tue.nl

[c] Faculty of Architecture, Building and Planning, Eindhoven University of Technology, Eindhoven, the Netherlands, l.c.havinga@tue.nl

Abstract. In the next decades the number of aging people living with dementia and requiring intensive care will increase significantly. With this increasing number, due to their frailty, new challenges arise, including a higher risk of infection due to long-range aerosols that contain pathogens. This study sought an answer to the question of how the risk of (potentially lethal) infection through such transmissions can be limited, and the quality of life improved. The study looked at improving the basic health of residents and at additional measures to reduce the risk of infection in long term care facilities (LTCF). The focus group within this research was demented aging people living in small scale care facilities with 24-hour guidance. By means of an iterative design process and the In2health method, a building design was realised in which additional measures concerning ventilation and air-cleaning were applied. These measures were tested against different future scenarios concerning the spread of viruses in LTCFs. Based on various calculations using the Wells-Riley method, it was concluded that the building design can reduce the risk of infection without affecting the quality of life. This, however, does take a lot of additional devices, services and measures per building. Further research should include measurements in long term care facilities to ensure the specific effectiveness of the measures. Furthermore, specific air quality regulations should be designed for long term care facilities, including calculations based on risk for infection.

Keywords. Health, ventilation, Covid-19, pathogen transmission, dementia, care facilities.
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1. Introduction

The number of aging people in the Netherlands rises quickly. Within that population, 280,000 persons are suffering from dementia, 80,000 of whom are currently living in nursing homes with intensive care. In the next 25 years, this number is expected to double[1]. When people are getting old, especially when having dementia, new challenges emerge, including 1) an alternative perception of an indoor environment, 2) a higher vulnerability to air pollution due to a declining immune system and weakened host defence, 3) and a sensitivity to too high and too low temperatures [2].

When focussing on indoor air quality (IAQ), not only poor air quality causes health issues, but air can also be seen as a transfer medium for pathogens and airborne diseases. As there are no specific guidelines for IAQ in Long Term Care Facilities (LTCF), it is still not well understood on how to create a healthy environment for this specific target group concerning the spread of infectious airborne diseases.

According to a research of Te Kulve et al. [3], the chance for an outbreak of an infectious disease in a LTCF depends on building characteristics, indoor air quality and the basic health of residents (based on underlying diseases). Subsequently, the spread can be divided into contact transmission and airborne transmission (long-range and short-range).

At the moment not much research has yet been conducted on designing small-care facilities for aging people with dementia, concerning the airborne transmission of infectious diseases. However, with the introduction of Covid-19 there has been an increasing discussion on the state of care homes in terms of indoor air quality, focused on the quality of life versus the chance for infection by airborne transmission [4].

Because there is a lack of research within the field of building design, this study looks at how the quality of life can be improved in a small care facility, minimising the risk of infection by long-range airborne transmission, while increasing the quality of life for aging people with dementia in a LTCF. The aim of the study is to identify design measures that contribute to limit the risk for infection, and with that develop a building design that takes both the building and services design into account, as well as the quality of life.

2. Method

The research is based on the In2Health [5] method and is divided into four different stages: 1) formulating the design challenge, 2) conceptual design, 3) embodied design and 4) detailed design. Formulating the design challenge consists of a literature review on the long-range transmission of airborne diseases, with Covid-19 as a case study. With the help of this literature review, Key Indoor Performance Indicators are formulated which form a guideline for the design of the building. In the concept design, embodied design and detailed design, an iterative process is followed, in which a small scale LTCF is designed, analysed, and evaluated into a final design. In this paper, the main outcomes of the literature review and the final design results are shown.

2.1 In2Health method

When working in a care-environment, many stakeholders are involved. This makes the design process complex and dynamic. However, a structured approach can be applied by making use of design-support models and evidence-based design. Evidence-based design is an approach for the design of health care facilities, basing design choices on scientific data [6]. A suitable method to implement evidence-based design in the design of healthcare environments is by making use of the In2Health-method [5], see Fig. 1. This philosophy looks into 'wholes' of technology, meaning that the building does not only function as a care facility, but also as a home and work environment. In Fig. 1 an overview is given of this method combined with the steps for an iterative design process. It makes use of three models: the ontology of Dooyeweerd, the International classification of functioning, disability and health (ICF) and the model of integrated building design (MIBD).

The ontology of Dooyeweerd states that first the disorder -which is in this case dementia- should be understood before the design process can be started. This is consistent with the concept of ICF, which looks at, in this case, environmental factors that affect human functioning. During this evaluation, both the perspectives of residents and care givers should be considered. As the study is conducted from a technical point of view, subject-specific knowledge on dementia is not investigated in depth. For this reason the tool OAZIS [7] combined with literature has been used whereby wishes and demands of a healing environment are translated into practical guidelines for designing a LTCF for aging people with dementia. Using this strategy, the disorder can be understood in a more practical way.

Next MIBD is applied (see Fig. 1). During this step a translation has to be made from the value framework to specific design strategies which contain the so-called six S's (stuff, space, services, skin, structure and site). The value framework indicates what the main purpose is of the building. It is a balance between the performances demanded by the user and performances delivered by the building.

The third step is the evaluation of the design per conceptual, embodied and detailed design to check if the building design meets the requirements set by the In2health method. Ultimately a final design is realized.

2.2 Stakeholders

Many stakeholders are involved in the design of a LTCF. As in this case the study is about the spread of long-range airborne diseases, the group of aging people with dementia is considered as most important as they should be protected from infectious diseases and a lacking IAQ on the one hand, and protected from social isolation to prevent high levels of stress and unmanageable behaviour by residents on the other hand [8]. Furthermore, preferences of care givers, including nurses and family, should be incorporated in the design too. The

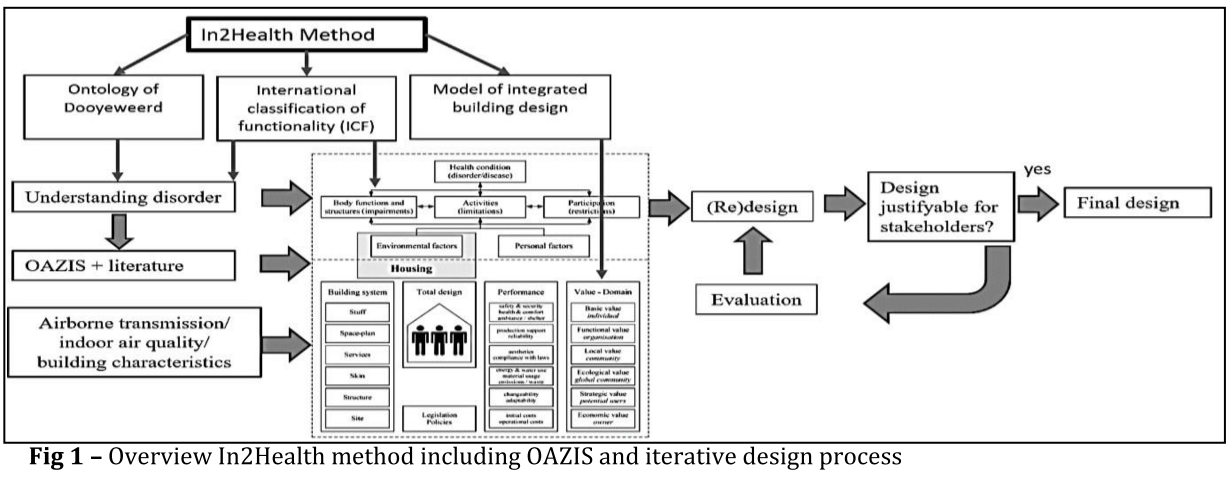

Fig 1 – Overview In2Health method including OAZIS and iterative design process main goal of this target group is to improve the quality of life of the residents by supporting them in their daily activities, independence and social care.

2.3 MIBD – value framework

The value framework in the MIBD model has a strong relationship with the stakeholders. Based on reference studies ([2], [5], [6]) it can be stated that the basic value and the functional value are most prominent for this case. The basic value includes safety & security, Health & Comfort, and Ambiance & Shelter. This value is based on the relationship between an individual and their sense of physiological and physical well-being. The functional value includes Production, Support & Reliability. It mostly focusses on how daily activities and care giving/taking processes, taking place in the building, are supported. For residents this means that the building should facilitate the resident's way of living and for caregivers it means that they should be able to provide care in the most optimal way [2].

3. Results

An iterative design process has been applied. In this paper the most important outcomes of the literature study and the final results are shown.

3.1 Literature review

Airborne diseases originating from humans can be spread through the air as droplets or aerosols. An aerosol is a collection of solid or liquid particles suspended in gas and can be spread by breathing, coughing and talking [9]. These particles can survive in the air within a range of a couple of hours to a couple of days, depending on their size [10]. It makes the transportation of airborne aerosols possible over a long distance. In this paper only long-range transmission is considered, which will be the case when an aerosol travels at least beyond the short-range distance of 1-2 meters and is controlled by the air. In this case the assumption is made that a fully mixed situation exists.

The focus of the study is on the spread of the SARS-CoV-2 virus, causing Covid-19 disease. It causes febrile respiration infection and atypical pneumonia and can be transmitted via the air.

Spread of airborne diseases

The movement of aerosols through space is influenced by two main mechanisms: 1) the expiratory flow and 2) dispersion via room air flow. The expiratory flow depends on human activities, including among other things: coughing, talking and breathing in a certain direction. The survivability of aerosols by dispersion via room air flow depends on room characteristics, including temperature, air circulation patterns and the operation of the HVAC system, possibly supported by local mitigation manners through air cleaning [11]. Relative humidity is less important for Covid-19, as effects only start to occur at humidity levels outside the normal comfort conditions, e.g. above 70% [12].

Taking a closer look at room characteristics, there are signs that the recirculation of air at building level by a heat recovery system may contribute to the spread of aerosols through the building [12]. Secondly, recirculation at room level can also be seen as a possible polluting source when no air cleaning methods are applied in the room. Furthermore, ventilation has an effect on the deposition of particles on surfaces [13] and determines the direction of air flow in the room [14]. Displacement ventilation can be considered as a more efficient option for ventilation. However, this method is not always better for the dispersion of aerosols at a long distance, because air particles can remain longer in a stratified layer of air [13]. Using mixed ventilation, contaminated air will be diluted while limiting the chance of a direct air flow between two person, assuming vortex flows will not occur in the room [15].

Indoor air quality (IAQ)

IAQ refers to the air quality within and around buildings and structures, with the health and comfort of building occupants in mind [16]. It includes different sorts of indoor chemicals or substances. The importance of each pollutant depends on its potential effect on health and, the emission rate into the (indoor) environment and at what time span: continuously or temporarily [17]. Furthermore, the accumulation of emissions also depends on the degree of ventilation in the building and the infiltration of outdoor conditions into indoors or from one room to another room [16].

The quality of the indoor air has an influence on the basic health of residents. The likelihood of getting ill from infectious diseases increases when a person's health is deficient [3]. Aging people experience a faster deterioration of immune defences and long function, resulting in an increased risk of infection. According to a study of Bentayeb et al. [18] risks for regular breathlessness and cough were found with an elevated level of PM_{10} and NO_2. Furthermore, a relation was found between COPD-type of symptoms and high ratios of $PM_{0.1}$. Even at low levels of pollution, the IAQ affected respiratory health of aging people permanently living in nursing homes. Additionally, there is a suspicion that there is a link between CO_2-levels >800 ppm, as proxy for the IAQ, and restlessness behaviour during sleep for people with Alzheimer's disease [19].

Guidelines indoor air quality

At present, no specific guidelines exist for the indoor air quality of a LTCF for aging people with dementia [3]. However, there are general guidelines that can be considered as a reference point. Using Praktijkboek Gezonde gebouwen [20] ventilation requirements, ventilation rates and limits for CO_2 can be set based on three classifications: A (very good), B (moderate), C (minimum – slightly better than Dutch Building decree). Ventilation rate class C has a minimum of 8.3 l/s p.p. (30 m^3/h), class B 11.1 l/s p.p. (40 m^3/h) and class A 17 l/s p.p. (60 m^3/h). For CO_2 the reference value for class A is 800 ppm (400 ppm outdoors + 400 ppm indoors).

To include risk for infection, the Wells-Riley method can be used. This method calculates the risk for infection and is divided into three categories in this study: <1%, 1-5% and 5-20% risk for infection [21], [22]. The chance for infection is the chance that a non-infected person will get infected in a room with one infected person.

Using this method, the needed mitigation options (e.g. ventilation rate) can be determined that have to be applied in the room to reduce the risk for infection. Limitations of the method include the uncertainty of the exact amount of quanta emitted by a person and it assumes a well-mixed ventilated room. Furthermore, peaks of the virus concentration are left out of consideration [21]. Therefore, the method only has been used as a method, to compare design solutions.

Design Long Term Care Facility

The physical environment has a significant influence on the perception of people with dementia [23]. Traditionally, the design of a LTCF can be directed towards a traditional nursing home ward or a small scale living. In this research the focus is on a stand-alone small scale care facility.

The fit between the environment and an individual's cognitive and physical activities is associated with the ability to age in place in a LTCF. This means that the building should be an environment that positively influences people's autonomy, support their quality of life and well-being, and attain the best possible potential of independence.

For the assessment of the building the tool OAZIS 1.0 has been used [7], [23]. This tool can be used to examine the effect of the building on the perception of residents and staff members, and gives guidelines for evaluating the design of a care institution. The model is based on evidence based design and the healing environment concept. Ultimately, this model is used to create a design that suits the wishes and demands of the resident the best. The statements being made in the OAZIS tool are validated with additional studies of Prevosth et al. [24], Verbeek et al. [25] and Heumen et al. [26].

OAZIS provides suggestions on different categories: 1) privacy and autonomy, 2) Nature, windows and view, 3) Comfort and control, 4) Facilities, 5) Orientation and Routing, 6) interior and 7) Staff. Within each category, different statements can be assessed using a 5-point system, where 5 stands for 'fully agree/ fully applied' and 1 for 'fully disagree/ not applied'. In the end, all the points in each category

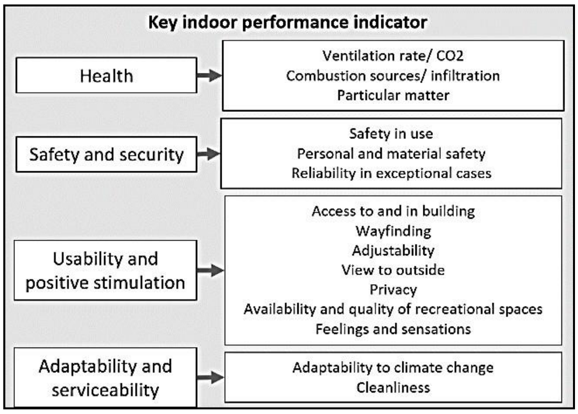

Fig 3 – Key indoor performance indicators

are added up and these determine the final score for the component. When making different variants for the building design, these different scores can therefore be compared in order to arrive at the most optimal design.

OAZIS only provides statements for creating a healing environment and does not give an indication on functional rooms and sizes. Therefore, additional studies ([25]–[29]) are used to determine the required room functions and room sizes in a small scale LTCF.

3.2 Scenario development

A standard LTCF design is based on a scenario when no residents are infected with an airborne disease. This is not always the case. It may happen that residents in the building are infected and can therefore infect others. A distinction can be made between diseases that are contagious, but do not immediately pose a serious risk to other residents and staff members (e.g. influenza virus and Norovirus), and a situation in which a deadly virus spreads, causing the possibility for both residents and caregivers to become seriously to lethally ill (e.g. Covid-19). In this research a design has been created that functions during normal and extreme cases. Therefore, three scenarios are defined, shown in Fig. 2.

1: Scenario: Alert

This scenario is based on a standard situation. The risk for infection is very low. Additional measures do not apply. However, residents are monitored for infections.

2: Scenario: Alarming

In this scenario one or multiple residents are infected with an essentially non-lethal airborne virus. In scenario 2A) an infected individual will be separated from the group for a short amount of time, or 2B) a

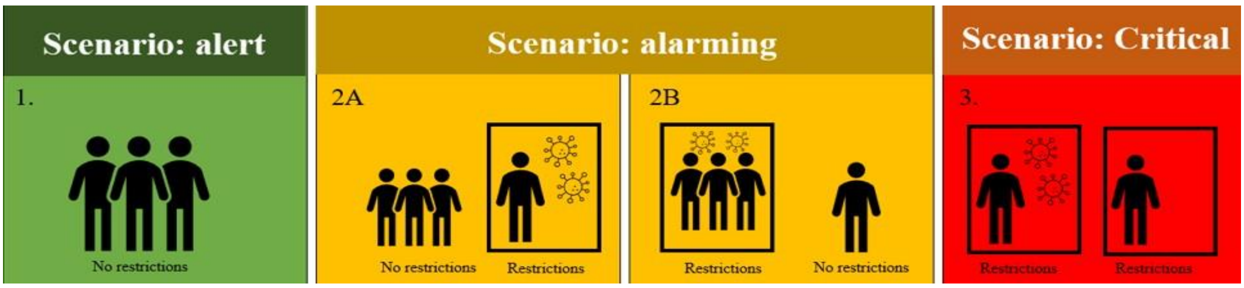

Fig 2 – Scenario development for possible future circumstances concerning restrictions for residents depending on the type of virus group of infected people will be separated from an individual.

3: Scenario: Critical
In this scenario, a pandemic like Covid-19 would occur. In this case, the number of people in a room and in contact with others should be limited as much as possible. This means that people should be separated from each other individually by keeping enough distance between residents, care takers and visitors. The risk for infection must be very low.

Ultimately, for each scenario, the best design solution is sought for preventing the spread of infectious diseases versus the quality of life. For this purpose, Key Performance Indicators are weighted against all scenarios, resulting in one best design solution.

3.3 Key Indoor performance indicators

In Fig. 3 a simplified version of the Key Indoor Performance Indicators (KIPI) is shown, with the most important indicators at the top of the figure. The KIPIs for health are evaluated based on: ‘minimum’, ‘moderate’ and ‘good’. For the other KIPIs the KIPIs are evaluated using the tool of OAZIS. For this tool inclusive data will be evaluated using the scale from one to five. The minimum standard is a score of 3/5, moderate a score of 4/5 and good a score of 5/5 per statement.

3.4 Model of integrated building design

In Fig. 4 the KIPIs are linked to the basic and functional values of the value framework of MIBD. Focus was given to private rooms of residents and communal spaces including the living and dining room.

Building design LTCF
On the left side of Fig.4 it is shown that the design of the building has a strong relationship with the KIPIs as presented in Fig. 3. Especially wayfinding [30], access in and around the building [24], simple adjustability of the building, personal privacy [7] and connectability are important aspects for the usability of the building and for the increase in autonomy and self management of aging persons with dementia. Concerning infections in the building, especially adjustability of the building is very important. Based on the scenarios shown in Fig.2, rooms are opened or closed. The restrictions that apply to autonomy and

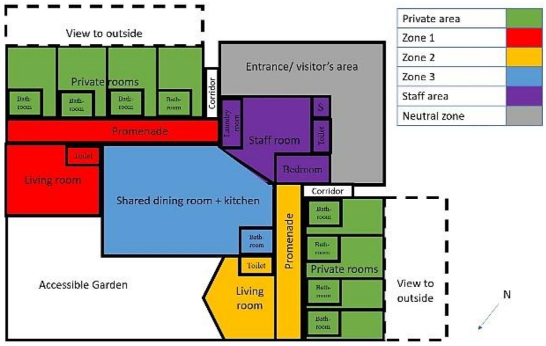

Fig 5 – Conceptual design (plan) for zoning in building. Private area: Private rooms/ isolation rooms; Zone 1/2: Communal space zone 1/2; Zone 3: Communal space that can be added to zone 1 or zone 2; Staff area: Staff room + functional rooms; Neutral zone: Zone where direction towards zone 1, zone 2 or staff area is determined.

self-determination, for instance the choice which room they enter, should be as natural as possible to improve the quality of life.

Ventilation design
The ventilation design has a direct link with the infection degree. When there are no infections in the building, standard guidelines can be applied. However, when scenario 2 or 3 occurs, the ventilation strategy has to shift towards ventilation based on risk of infections. The spread of air should also be on personal level and the interaction with other rooms should be included as well. To set reasonable limits for the risk for infection, the results as shown in Tab.1 are used.

3.5 Final design and strategies

Concluding from the previous sections, the building must not only meet the conditions concerning usability and autonomy, but must also reduce the risk of infection by improving the indoor air quality

For the building design zoning must be used in order to separate infected residents from non-infected residents, when needed. In this study a building design concept is created as an example how different zones in a building can be included. In Fig.5 an overview of the design is shown.

In scenario 1 (alert) zone 1, zone 2 and zone 3 are accessible for all residents. They can move freely through the building. In scenario 2A, the infected person remains in the private area, while other

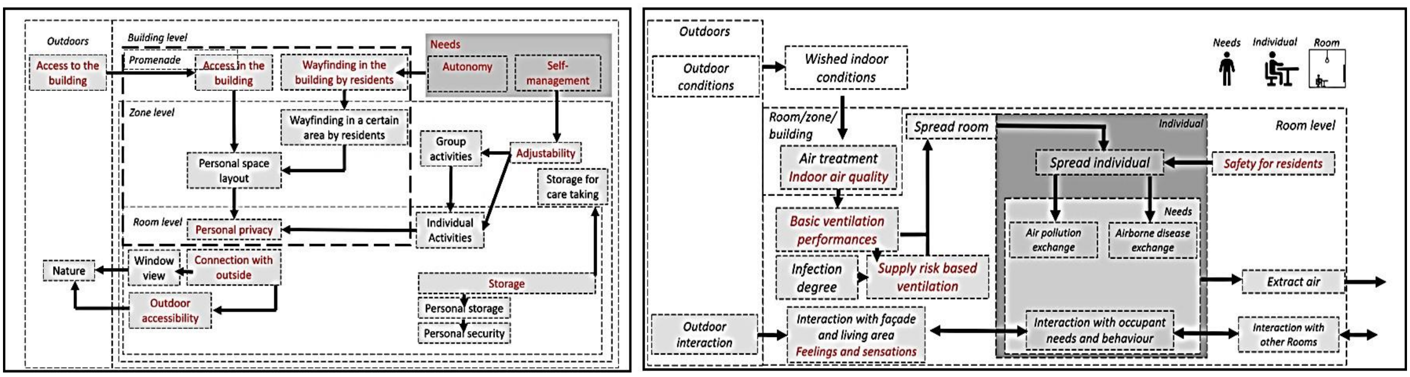

Fig 4 – Key Indoor Performance Indicators linked to Model of integrated building design residents can enter the same zones as in scenario 1. In scenario 2B, the building can be split into two zones, where a distinction can be made between zone 1 and zone 2, and partially zone 3. Zone 3 can be split in half to create a dining space for both zones. In scenario 3, all zones will be separated, so that a limitation in number of persons per room can be guaranteed. In this case non-infected residents can meet visitors in a separated communal room or in their private room. The zones can be created using moveable walls and closing doors.

For the ventilation design in scenario 1, ventilation calculations are based on the maximum allowable CO_2-levels set to class A of praktijkboek gezonde gebouwen [20]. For scenarios 2 and 3, calculations are based on the Wells-riley equation and linked to a risk for infection (RFI) specified for each scenario. In Tab. 1 an overview is shown of a potential RFI that can be applied per scenario. This, however, strongly depends on the wishes and demands of the building owners and occupants. Considering scenario 1, the maximum value of CO_2 in the room is set to 800 ppm, which comes down to a ventilation rate of 17 l/s per person based on a CO_2-production of 0.005 l/s per person [20]. For aging people this rate can be lower 0.0034 – 0.0041 l/s p.p. depending on the body activity.

For scenario 2A, 2B and 3 various calculations have been made. Using only ventilation in the building as the main source of limiting the risk of infection, very high ventilation rates are needed. In case of this design challenge, the ventilation rates are set to 120 l/s in private rooms for which an infection risk of <1% has been set during a 1-hour visit. When using 17 l/s per person, a maximum of 2 visitors in the room and an infection risk set to 1%, only a visit by family or staff of 30 minutes is possible. This, however, does not improve the quality of life, which means that additional measures have to be taken. This can be done using air cleaning methods. In total five different air cleaning methods are investigated: 1) Portable Air purifier with HEPA filter ($\overline{CADR}$: 361 m3/hr [31]), 2) Huv: HEPA Air Cleaner with UV-ABC lamps. ($\overline{CADR}$: 934 m3/hr.), 3) cHuv: Ceiling mounted HEPA Air Cleaner with UV-C lamps ($\overline{CADR}$:: 1700 m3/hr.), 4) UVGI: upper-room Ultraviolet germicidal irradiation ($\overline{CADR}$:: 1392 m3/hr.), 5) Huv-MP UVGI@100%($\overline{CADR}$: 2373 m3/hr). The ventilation rate in the room remains at a full capacity of 17 l/s per person. The main ventilation method is mixed ventilation complemented with personalized ventilation in the private rooms and dining rooms.

Ultimately, two results can be obtained for the private rooms and the communal spaces. In scenario 2A a HuV-MP UVGI@100% system will be turned on in all rooms combined with ventilation turned at full capacity. In the infected room the UVGI-system will be combined with a Huv system and the air lock - in terms of low pressure (-) in the infected room and high pressure (+) in the hallway of a private room - will be turned on. This increases the visiting time in the room to 4 hours at a 1% risk of infection. In the communal spaces the cHuv system will be turned on. the communal spaces up to 16 hours at a 5% risk of infection, which creates a normal environment for non-infected residents.

In scenario 2B multiple residents are infected with a non-lethal disease. In this scenario the CO_2-based ventilation will be switched to risk-based controlled ventilation. This also means that windows may not be opened anymore, due to the fact that the building will be regulated using (extreme) under and over pressure. In all the private rooms the UVGI-system should be turned on and in the infected rooms a Huv system should be placed and airlocks - in terms of low pressure (-) in the infected room, high pressure (+) in the hallway of a private room and higher pressure (++) in the hallways between the apartments - should be turned on to create an air barrier between the corridor and the private rooms. In the communal spaces it depends on the risk of infection set and the activities in the building what system should be turned on. Assuming that the cHuv-system will be turned on per zone, a 2-hour visit may be possible with a 1%risk of infection and a 11-hour visit may be possible with a 5% risk of infection.

In scenario 3 in all private rooms the HuV-MP UVGI@100% system will be turned on. When residents receive visitors, a Huv system can be placed inside the room. For the infected rooms, the air lock will be turned on. Furthermore, both living rooms will be closed. When visitors want to come by, they have to be sent to the private rooms. This option is more beneficial concerning infection rates than using all communal spaces. Furthermore, both dining rooms will be separated from each other. By using a cHuv system, 4 residents and 2 staff members can dine together as a 2-hour visit to the dining room is possible, assuming the infection risk. This prevents total social isolation. Note that assumed risk for infection is only possible when the distance between residents is large enough. Short-range and contact transmission are not included in the design.

Discussion

The main goal of this research was to see what design measures must be taken to limit the risk for infection in a LTCF as much as possible. In addition, the design

Tab 1 - Ventilation based on praktijkboek gezonde gebouwen (PGG) and risk for infection (RFI) linked to scenario 1, 2A, 2B and 3.

	Scenario 1	Scenario 2A	Scenario 2B	Scenario 3
Private bedroom	Fully accesible Ventilation: PGG	RFI: <1% in infected rooms <5% in non-infected rooms	RFI: <1% when multiple persons are infected.	RFI: <1%.
Dining room	Fully accesible Ventilation: PGG	RFI: 5-20% Restricted for infected residents	RFI: 1-5% Restricted for infected residents	RFI: <1%.
Living room	Fully accesible Ventilation: PGG	RFI: 5-20% Restricted for infected residents	RFI: 1-5% Restricted for infected residents	RFI: <1%.

should contribute to a good quality of life, which is why the human perspective is the most important starting point. When other starting points, such as acquisition costs, energy consumption or the flexibility of the system, are regarded more important, this research is no longer entirely relevant. It is therefore necessary to consider what the focus will be when designing a building, as this has a major effect on the applicability of systems. This also accounts for the risk of infection. Using strict measures to keep the risk for infection as low as possible asks for major interventions in a building. It depends on the stakeholders which measures should be taken to see which chance of infection best suits the situation.

Secondly, the calculations are based on the wild variant of SARS-CoV-19 of October 2020 [22]. Other variants of the virus have emerged in the meantime that are more (or less) infective. This indicates that when sizing systems a position should be taken on the infectivity when using the Wells-Riley method for a design. The method for designing such a building including the risk of infection, however, does not change.

Thirdly, the method explains the In2Health Method. The In2Health method is a derivative of the Model of Integrated Building Design (MIBD). The method describes that an in-depth investigation of the client's requirements must first be carried out, before design principles are adopted that relate to the design of the building. This in-depth investigation is supported by the OAZIS tool. This tool is a basic tool in which the starting points of a healing environment are included in the design. Because these are basic assumptions, a number of statements have been expanded with literature studies. Because the OAZIS tool is based on practical experiences in cooperation with research agencies, and because the basic assumptions in the tool are based on a literature study, it is assumed that it is a valid tool in the context. A note on the OAZIS tool is that it is based on a scoring system where points need to be allocated. By linking the scoring to the literature study, the validity of the results can be determined to some extent. It is assumed that the tool gives enough handles to make a design with this system, which makes the method of the study valid.

Conclusion

Using the In2Health method and the Wells-riley method, a solution was sought for reducing the risk of infection in a small-scale long-term care facility. A number of conclusions can be drawn:

- In order to reduce the risk of infection, the indoor air quality should already be at a healthy level to maintain the basic health of the residents and thus prevent a more serious risk of infection.
- Different scenarios should be considered when designing the building. The building must be able to adapt quickly to these changing scenarios at building and ventilation level.
- By using the In2Health method in combination with MIBD and OAZIS, targeted solutions can be devised that meet the needs of the residents and carers.
- The Wells-Riley method can be used to calculate the risk of infections. This has shown that extra sink terms, such as the cHuv and Huv-MP UVGI@100% system, reduce the risk of infection in residents and increase the visiting time. This increases the quality of life and reduces the risk of infection. Only using ventilation as a strategy does not fulfil the requirements under severe circumstances, given the infectivity assumed.
- The risk of infection drastically affects the visiting time and the additional measures. Therefore, it is important to talk to the stakeholders to see what infection risk is regarded acceptable.
- For the building design, a combination of different systems was made. This combination fits best when designed from a health perspective.
- The final design satisfies requirements concerning health. For the requirements on energy, purchase costs and maintenance, this design is not the best option and could therefore be improved.
- In the upcoming years more attention should be paid to specific guidelines for long term care facilities including ventilation rates and additional measures to 1) keep the air as clean as possible to maintain health of residents at a high level and 2) to limit the chance for infection using for instance calculations based on the Wells-Riley method.
- This study focuses on long-range transmission of aerosols. A completely mixed situation has been assumed, so that the Wells-Riley method could be applied. Situations also occur in a nursing home in which short-range transmission takes place. This falls outside the scope of this study, but could be a good addition for a follow-up study by modelling such issues. Combined results of long-range and short-range transmission have the potential to lead to a more realistic result in practice. However, solely modelling long-range emissions can already gives some insight in the drastic measures that are needed to create both a healthy and practical home environment.

Data access statement

Data sharing is not applicable to this article as no datasets were generated or analysed during the current study.

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