SUstainable solutions for affordable REtroFIT of domestic buildings

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Results of indoor environment modelling

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Disclaimer

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Abbreviations

SAHP	Solar assisted heat pump
GSHP	Ground source heat pump
TP	Thermal pipe
DX	Direct expansion
PV	Photovoltaic
HWT	Hot water tank
DHW	Domestic hot water
COP	Coefficient of performance
GHE	Ground Source Heat Exchanger
PMV	Predict Mean Vote

Publishable summary

This report is focused on computer modelling of the indoor environmental quality before and after renovation based on real climatic and occupancy conditions. Results will be compared with occupants' survey to assist the assessment of their satisfaction on the renovated buildings.

A research paper with title "CFD modelling of indoor thermal comfort with integrated building retrofit technologies: validation and case study" has been prepared and intended to submit to Journal of Energy Conversion and Management.

Introduction

Leading Beneficiary: University of Nottingham (UNOTT)

Participants: Instituto de Soldadura e Qualidade (ISQ)

Task description:

Task 2.3: Results of indoor environment modelling (UNOTT, M1-M15)

• Indoor Environment computer model development for simulation of the indoor environment in domestic buildings (by UNOTT, M1-M15). Computer modelling of the indoor environmental quality will be carried out for the buildings before and after renovation based on real climatic and occupancy conditions. Results will be compared with occupants' survey to assist the assessment of their satisfaction on the renovated buildings. Computational fluid dynamics will be used to investigate the air flow and heat and contaminant movement in the buildings. Models and boundary conditions unique with the project which may not be readily available in existing software such as heat transfer through innovative insulation materials will also be developed. In addition, daylight quality in the buildings will be investigated.

In this deliverable, the comfort criteria of indoor air temperature, moisture content, indoor air speed, CO_2 distribution and PMV index will be detailed.

1 Summary

To better understand the model that produces values for the predicted mean vote (PMV) [1] and the predicted percentage of dissatisfied (PPD) [2], we should start at the beginning, with the man who created them, Povl Ole Fanger. He hypothesized that human thermal comfort was based on one's skin temperature and their sweat secretion, and that one could only be considered 'comfortable' if these two factors were balanced within a narrow range of acceptability.

As humans, our thermoregulatory system modifies our temperature through involuntary responses. For example, by sweating in high temperatures or shivering in cold temperatures to keep us thermally balanced and to avoid local discomfort. The human body can adapt to the external environment up to a certain range, but as soon as the limits are reached, the body's responses are perceived as uncomfortable. Through climate chamber experiments, Fanger's [2] theory evolved to declare that thermal comfort could be found from evaluating the metabolic rate, clothing insulation and environmental conditions of an individual (Figure 1).

Figure 1 Environmental and personal factors that influence thermal comfort

Today, thermal comfort is defined as "that condition of mind that expresses satisfaction with the thermal environment" in the globally recognized ASHRAE 55 [3] and ISO 7730 [2] standards for evaluating indoor environments. To assess this condition, engineers must first determine the thermal sensation or thermal balance inhabitants of an indoor environment may feel in tangent with the thermal dissatisfaction experienced by occupants. These comfort limits can be expressed by the PMV and the PPD indices.

PMV is an index that aims to predict the mean value of votes of a group of occupants on a seven-point thermal sensation scale (Figure 2). Thermal equilibrium is obtained when an occupant's internal heat production is the same as its heat loss. The heat balance of an individual can be influenced by levels of physical activity, clothing insulation, as well as the parameters of the thermal environment. For example, thermal sensation is generally perceived as better when occupants of a space have control over indoor temperature (i.e., natural ventilation through opening or closing windows), as it helps to alleviate high occupant thermal expectations on a mechanical ventilation system.

Within the PMV index, +3 translates as too hot, while -3 translates as too cold, as depicted below.

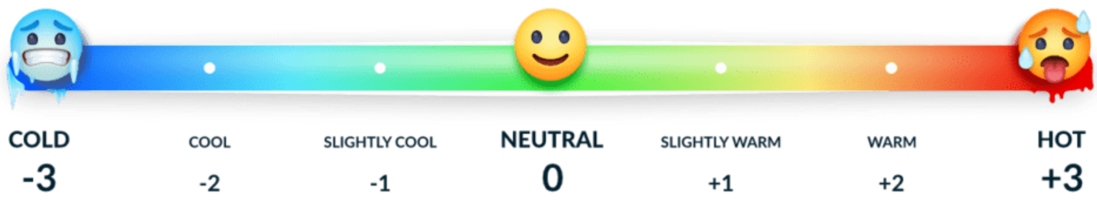


Figure 2 PMV index

Different methods outlined in the ASHRAE 55 and ISO standards for certain types of environments can be used to assess and gather information for various combinations of metabolic rate, insulation, temperature, airspeed, mean radiant temperature, and relative humidity that factor into PMV. In order to compute the PMV, the simulated temperature and airspeed velocity (i.e., the ASHRAE/ISO standards recommend to make an adaption for speeds above 0.2m/s) of a given environment are used as inputs. These variables, along with given inputs for clothing insulation, relative humidity, and mean radiative temperature provide the basis to calculate PMV. Using both of these indices, ASHRAE 55 dictates that thermal comfort can be achieved based on 80% occupant satisfaction rate or more. The remaining percentage of people can experience 10% dissatisfaction based on whole-body discomfort (all listed influencing factors of PMV) and 10% dissatisfaction based on local discomfort/partial body discomfort (includes fewer factors than whole-body). In order to comply with ASHRAE 55, the recommended thermal limit on the 7-point scale of PMV is between -0.5 and 0.5. ISO 7730 expands on this limit, giving different indoor environments ranges. ISO defines the hard limit as ranging between -2 and +2, for existing buildings between -0.7 and +0.7, and new buildings ranging between -0.5 and +0.5. The PPD can range from 5% to 100%, depending on the calculated PMV. These comfort values will vary depending on where the occupant is located in the building. In order for comfort ranges to comply with standards, no occupied point in space should be above 20% PPD (Figure 3).

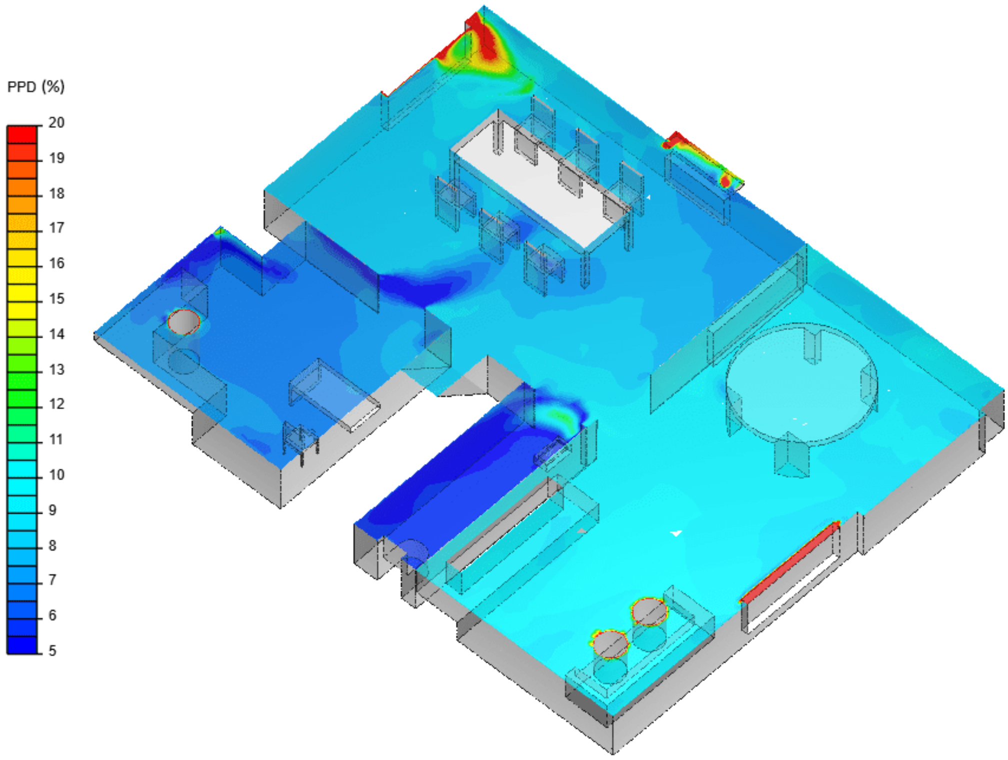


Figure 3 The predicted percentage of dissatisfied (PPD) index provides an estimate of how many occupants in a space would feel dissatisfied by the thermal conditions. All occupied areas in a space should be kept below 20% PPD in order to ensure thermal comfort according to the known standards (ASHRAE 55 and ISO 7730).

As a design or construction engineer, ensuring thermal comfort is often one of the prime objectives. So far, the success of this depended heavily on personal experience and the applicability of common methods for estimations. PMV and PPD can simply not conclusively be predicted in advance. With the emergence of engineering simulation tools in recent years, the guesswork has been removed from the equation, enabling anybody to test and optimize any given environment for thermal comfort compliance easily. Based on these environmental and personal (clothing, metabolic rate) inputs, SimScale provides thermal comfort parameter outputs in the form of PMV and PPD fields, following the static model for determining the thermal comfort in a space. To learn more, refer to our Thermal Comfort Parameters documentation. In order to comply with comfort standards, the aforementioned given ranges for each index must be met and additional influencing conditions must be acknowledged. Achieving thermal comfort of an environment is an innately cumbersome task, as thermal environments of a space can change over time and recommended limits cannot always be met; especially with the onset of climate change and unpredictable weather patterns. While it is scientifically impossible to fully please everyone, the purpose of these indices is to try to please 80% of occupants in a given space, while mitigating factors that cause overwhelming discomfort.

Table 1 defined the indoor comfortable level with different temperature and relative humidity, with 7 categories of temperature range and 6 categories of relative humidity, which can be simply divided into three attitudes, including unpleasant, acceptable, and comfortable. The comfortable zone is defined as the temperature varied between 20 and 22 with relative humidity varied between 40% and 60%. The acceptable zone is defined as the temperature varied between 18 and 24 with relative humidity varied between 30% and 70%. Besides, any point of air state exceeds the acceptable zone will make people feel unpleasant. Therefore, this report will apply the definition of the comfortable degree to make assessments to the indoor thermal environment of the simulated post-retrofit building performance.

Table 1 Comfortable level definition of temperature and relative humidity

T		RH	
<18	Cold, unpleasant	>80%	damp, unpleasant
18-19	Cold, acceptable	70%-80%	slightly damp, unpleasant
19-20	Slightly cold, acceptable	60%-70%	Slightly damp, acceptable
20-21	Comfortable, pleasant	50%-60%	Comfortable, pleasant
21-22		40%-50%	
22-23	Slightly warm, acceptable	30%-40%	slightly dry, acceptable
23-24	Warm, acceptable	<30%	dry, unpleasant
>24	Hot, unpleasant		

2 Baseline model and grid setup

2.1 Baseline model and grid setup

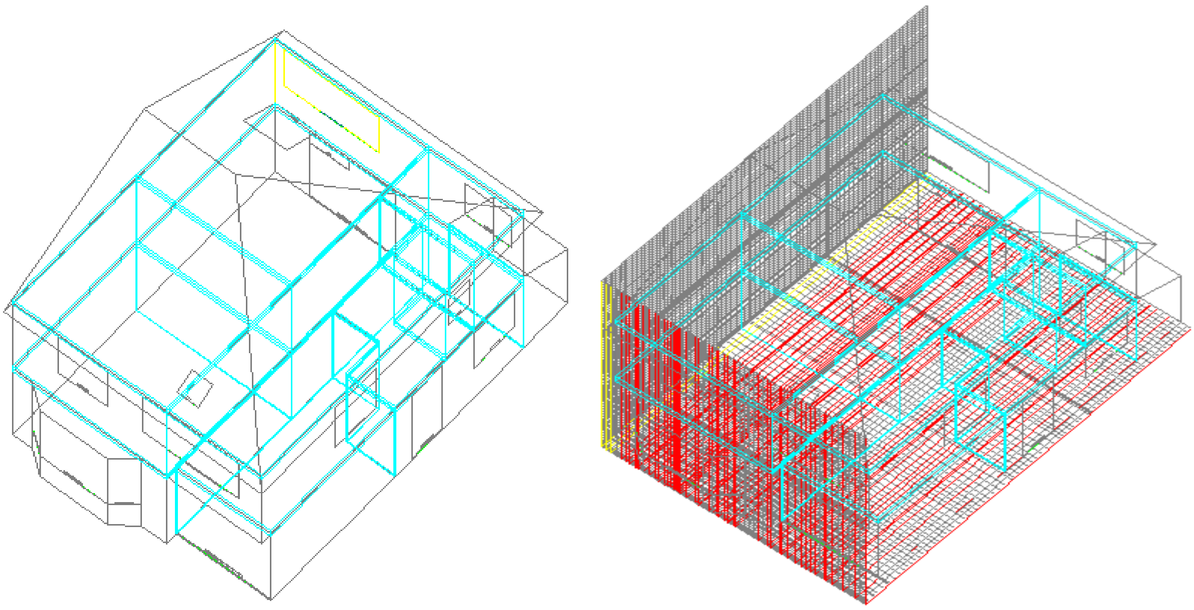
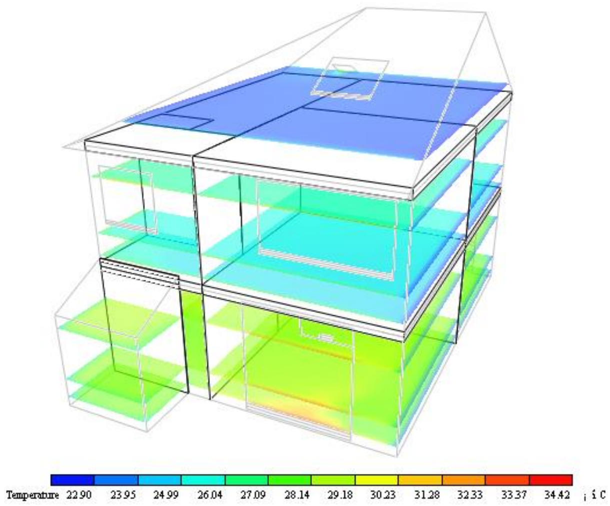


Figure 4. Model geometry and Mesh generation

2.2 Baseline comfort assessment (Indoor air temperature)

In summertime, the baseline comfort, the maximum indoor air temperature is 31.01℃, the minimum indoor air temperature is 27.93℃, and the average indoor temperature is 29.00℃. the maximum ΔT is 3.08℃. Figure 5 shows the detailed indoor air temperature distribution in summertime.

In wintertime, the baseline comfort, the maximum indoor air temperature is 14.89℃, the minimum indoor air temperature is 6.00℃, and the average indoor temperature is 13.17℃. the maximum ΔT is 8.89℃. Figure 6 shows the detailed indoor air temperature distribution in wintertime.



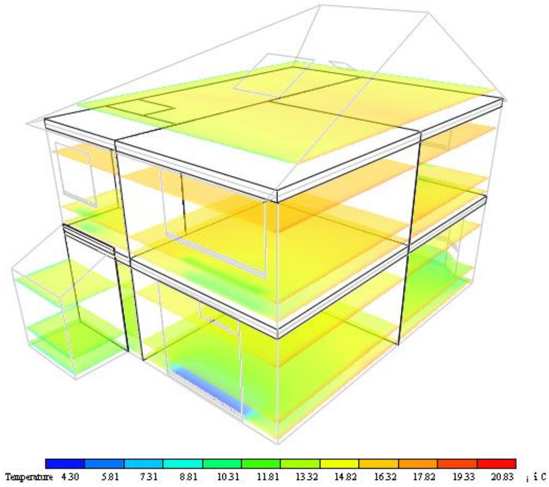


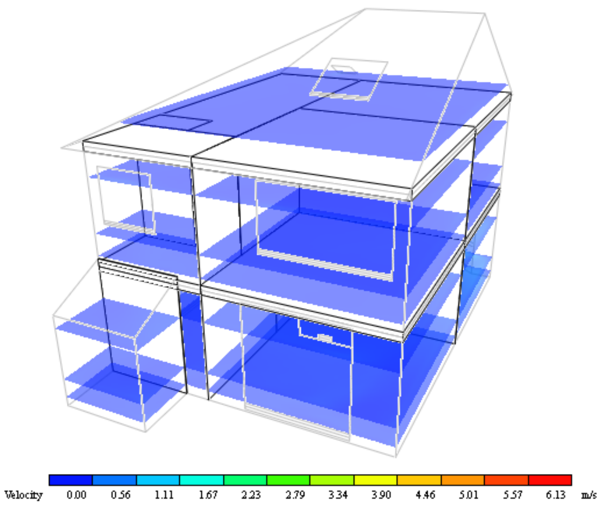
Figure 5 indoor air temperature distribution in summertime when using base model.

Figure 6indoor air temperature distribution in wintertime when using base model.

2.3 **Baseline comfort assessment** (**Indoor air velocity**)

In summertime, the baseline comfort, the maximum indoor air speed is $0.22\ m/s$, the minimum indoor air speed is $0\ m/s$, and the average indoor speed is $0.1\ m/s$. the maximum $\Delta\boldsymbol{v}$ is $0.22m/s$. Figure 7 shows the detailed indoor air velocity distribution in summertime.

In wintertime, the baseline comfort, the maximum indoor air speed is $0.19\ m/s$, the minimum indoor air speed is $0\ m/s$, and the average indoor speed is $0.04\ m/s$. the maximum $\Delta\boldsymbol{v}$ is $0.19\ m/s$. Figure 8 shows the detailed indoor air velocity distribution in wintertime.



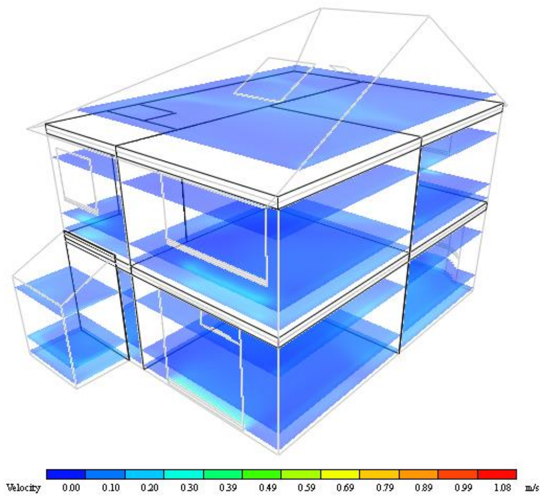


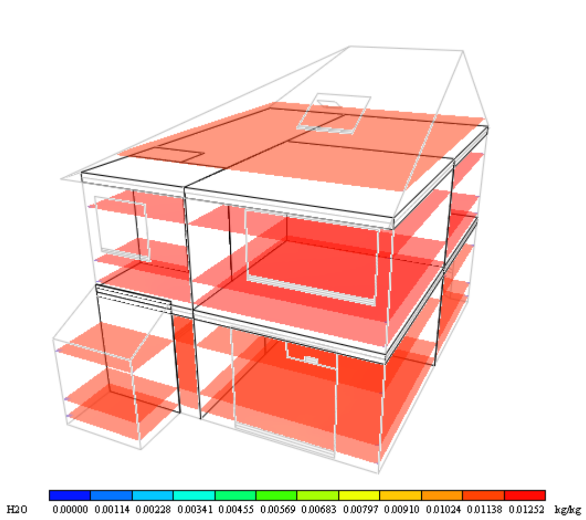
Figure 7indoor air velocity distribution in summertime when using base model

Figure 8indoor air velocity distribution in wintertime when using base model

2.4 Baseline comfort assessment (Indoor moisture content)

In summertime, the baseline comfort, the maximum humidity is 12.52 g/kg. Figure 9 shows the detailed indoor moisture content distribution in summertime.

In wintertime, the baseline comfort, the maximum humidity is 5 g/kg. Figure 10 shows the detailed indoor moisture content distribution in wintertime.



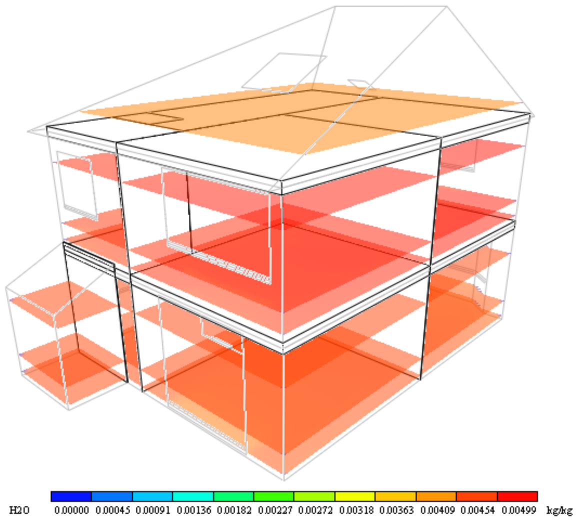


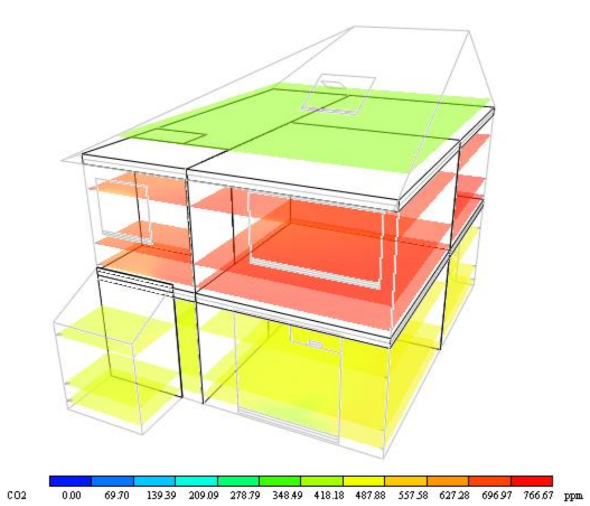
Figure 9Idoor moisture content distribution in summer time when using base model

Figure 10Indoor moisture content distribution in winter time when using base model

2.5 Baseline comfort assessment (Indoor Co2)

In summertime, the baseline comfort, the maximum CO_2 is 766ppm. Figure 11 shows the detailed indoor Co2 distribution in summertime.

In wintertime, the baseline comfort, the maximum CO_2 is 766ppm. Figure 12 shows the detailed indoor CO_2 distribution in wintertime.



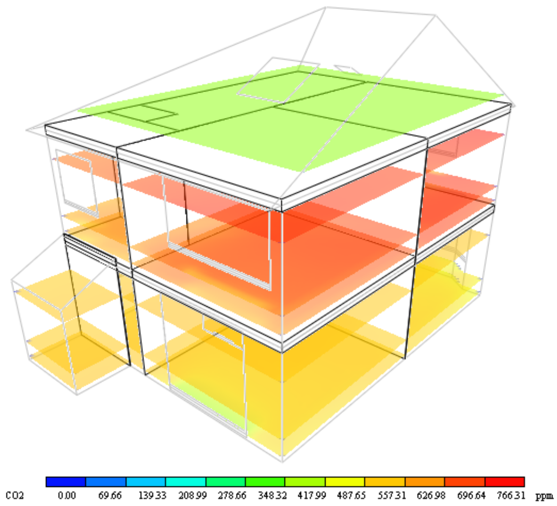


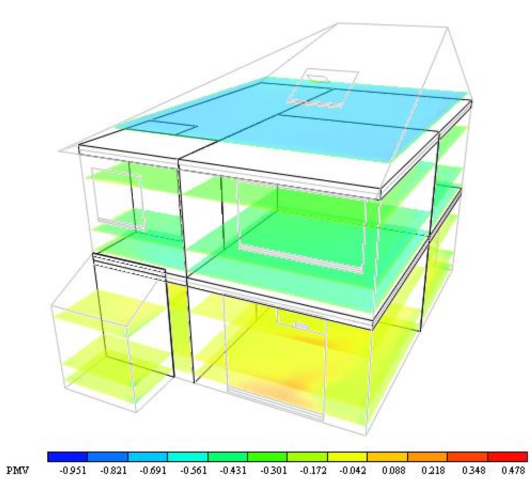
Figure 11 Indoor Co2 distribution in summer time when using base model

Figure 12 Indoor Co2 distribution in winter time when using base model

2.6 Baseline comfort assessment (PMV)

In summertime, the baseline comfort, the average PMV is -1.0. Figure 13 shows the detailed PMV distribution in summertime.

In wintertime, the baseline comfort, the average PMV is -1.9. Figure 14 shows the detailed PMV distribution in wintertime.



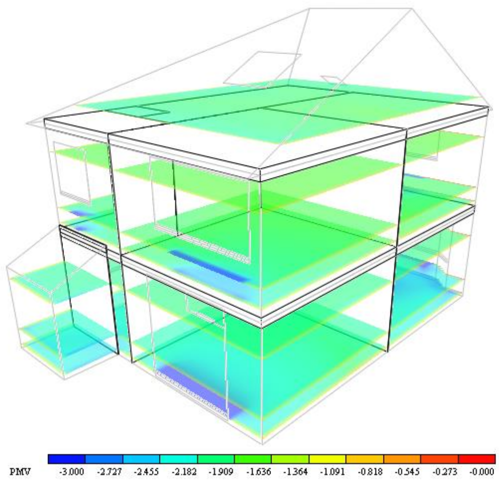


Figure 13 PMV distribution in summer time when using base model

Figure 14 PMV distribution in winter time when using base model

3 Silica aerogel interior insulation blanket Background

Silica aerogel interior insulation blanket has been adopted in this study for comfort analysis. Three different thicknesses are used to compare the perfomance.

3.1 Indoor air temperature when using Silica aerogel interior insulation blanket

In 5mm thickness, the maximum indoor air temperature is 15.01℃, the minimum indoor air temperature is 6.09℃, and the average indoor temperature is 13.42℃. the maximum $\Delta \boldsymbol{T}$ is 9.01℃. Figure 15 shows the detailed indoor air temperature distribution when using 5mm Silica aerogel interior insulation blanket.

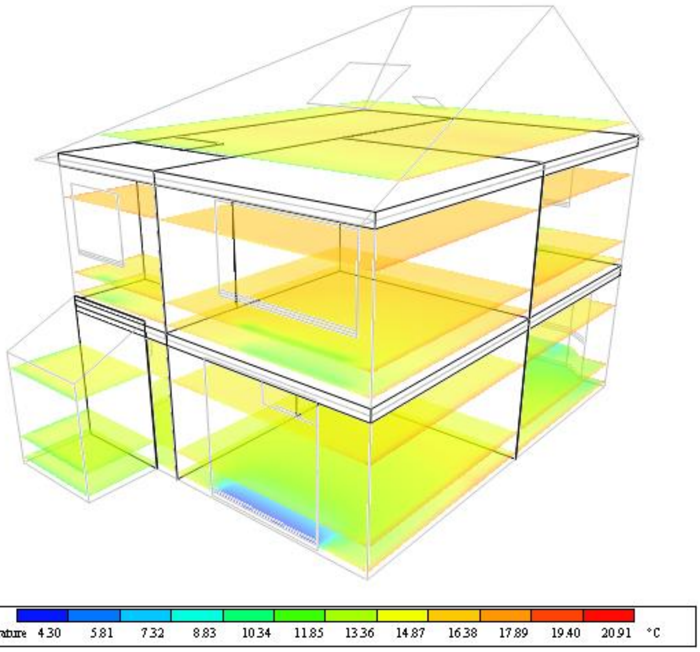


Figure 15Indoor air temperature distribution when using 5mm Silica aerogel interior insulation blanket.

In 15mm thickness, the maximum indoor air temperature is 16.44℃, the minimum indoor air temperature is 8.02℃, and the average indoor temperature is 15.67℃. the maximum $\Delta \boldsymbol{T}$ is 8.24℃. Figure 16 shows the detailed indoor air temperature distribution when using 15 mm Silica aerogel interior insulation blanket.

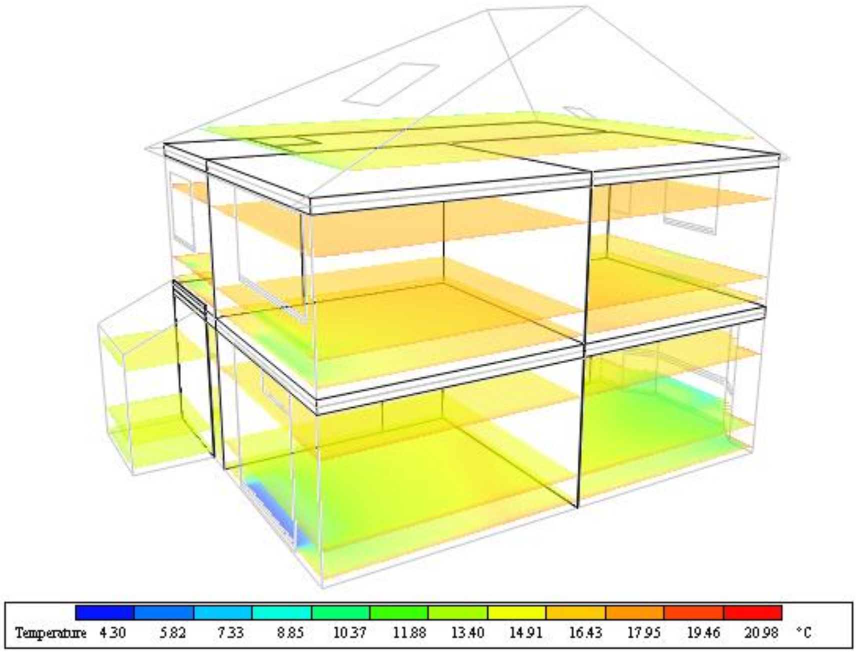


Figure 16 Indoor air temperature distribution when using 15 mm Silica aerogel interior insulation blanket.

In 30 mm thickness, the maximum indoor air temperature is 18.40℃, the minimum indoor air temperature is 10.76℃, and the average indoor temperature is 17.51℃. the maximum $\Delta \boldsymbol{T}$ is 7.64℃. Figure 17 shows the detailed indoor air temperature distribution when using 30 mm Silica aerogel interior insulation blanket.

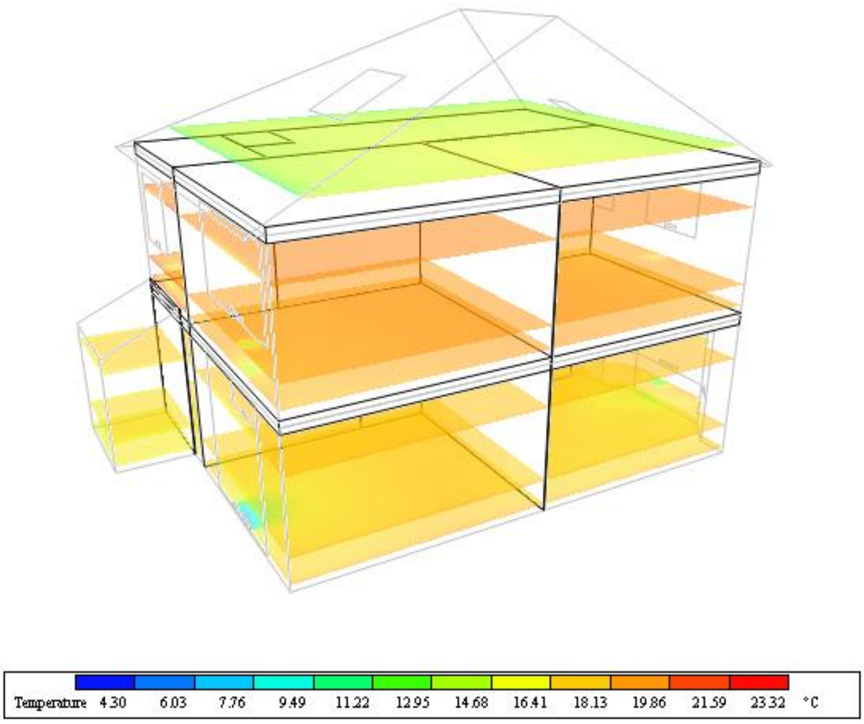
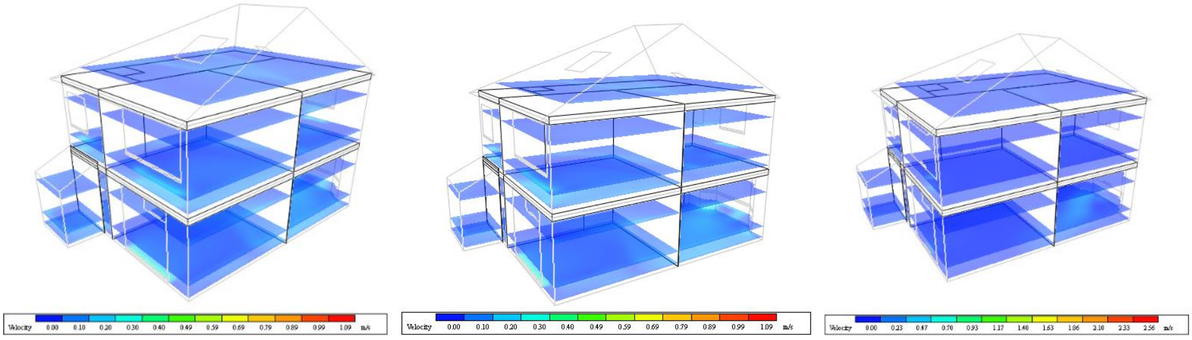


Figure 17 Indoor air temperature distribution when using 30 mm Silica aerogel interior insulation blanket.

3.2 Indoor air velocity when using Silica aerogel interior insulation blanket

Air speed do not change the performance with silica aerogel interior insulation blanket in difference thicknesses. The maximum indoor air speed is $0.19\ m/s$, the minimum indoor air speed is $0\ m/s$, and the average indoor speed is $0.4\ m/s$. the maximum $\Delta \boldsymbol{v}$ is $0.19 m/s$. Figure 18 shows the detailed indoor air velocity distribution in three difference thicknesses.



(a)5mm thickness (b)15mm thickness (c)30mm thickness

Figure 18 Indoor air velocity distribution in three difference thicknesses when using Silica aerogel interior insulation blanket

3.3 Indoor moisture content when using Silica aerogel interior insulation blanket

In 5mm thickness, the maximum indoor air humidity is $5.0 g/kg$, the minimum indoor air humidity is $2.8\ g/kg$, the maximum $\Delta hc\ is 2.2 g/kg$. Figure 19 shows the detailed indoor air humidity distribution when using 5mm Silica aerogel interior insulation blanket.

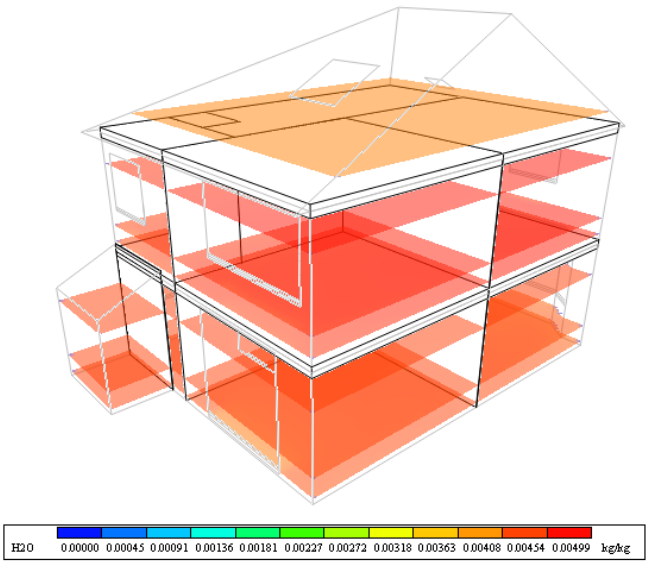


Figure 19 Air humidity distribution when using 5mm Silica aerogel interior insulation blanket

In 15mm thickness, the maximum indoor air humidity is $5.0g/kg$, the minimum indoor air humidity is $3.1\ g/kg$, the maximum $\Delta hc\ is\ 1.9g/kg$. Figure 20 shows the detailed indoor air humidity distribution when using 15mm Silica aerogel interior insulation blanket.

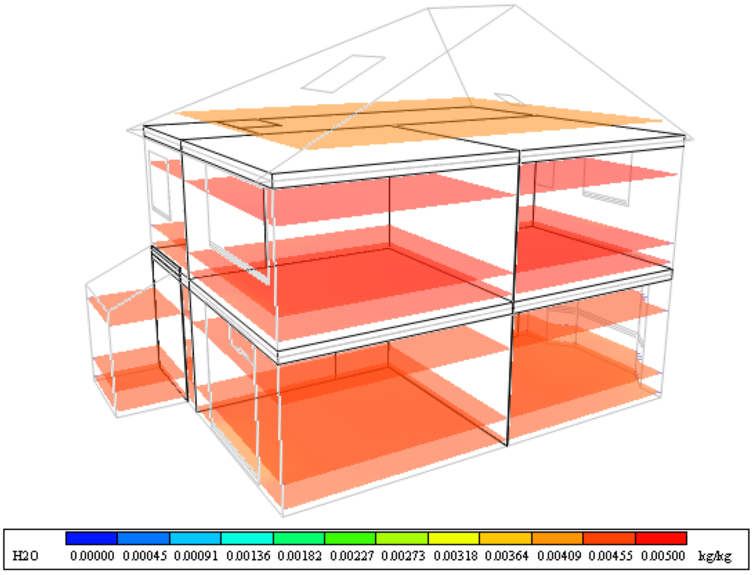


Figure 20 Indoor air humidity distribution when using 15mm Silica aerogel interior insulation blanket

In 15mm thickness, the maximum indoor air humidity is $6.2\ g/kg$, the minimum indoor air humidity is $4.5\ g/kg$, the maximum $\Delta hc\ is\ 1.7g/kg$. Figure 21 shows the detailed indoor air humidity distribution when using 30mm Silica aerogel interior insulation blanket.

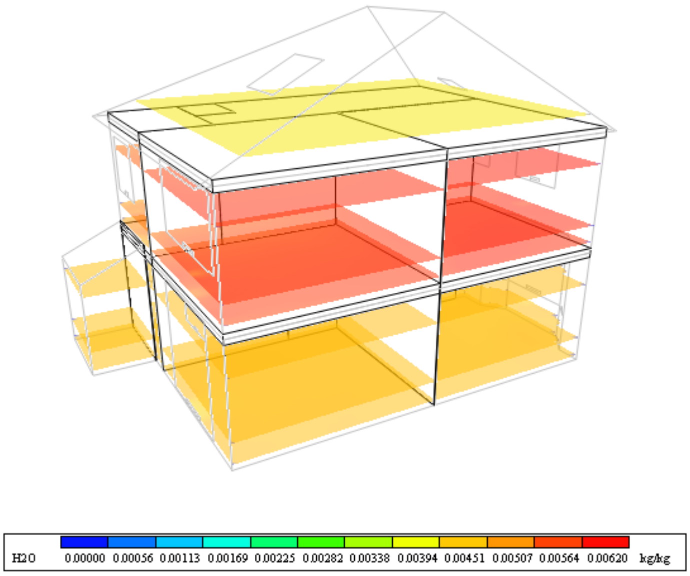


Figure 21 Air humidity distribution when using 30mm Silica aerogel interior insulation blanket

3.4 Co2 distribution when using Silica aerogel interior insulation blanket

In 5mm thickness, the maximum indoor Co2 is 765PPM, the minimum Co2 is 417PPM, the maximum $\Delta Co2\ is\ 348PPM$. Figure 22 shows the detailed indoor Co2 distribution when using 5mm Silica aerogel interior insulation blanket.

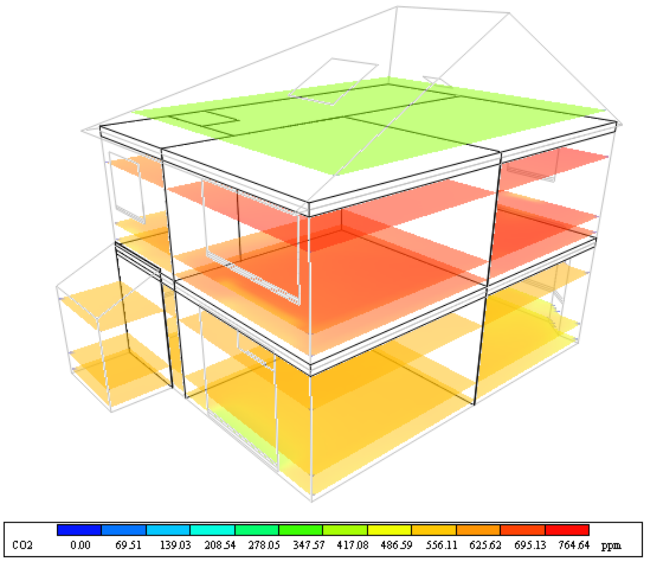


Figure 22 Indoor Co2 distribution when using 5mm Silica aerogel interior insulation blanket.

In 15mm thickness, the maximum indoor Co2 is 769PPM, the minimum Co2 is 417PPM, the maximum $\Delta Co2\ is\ 352PPM$. Figure 23 shows the detailed indoor Co2 distribution when using 15mm Silica aerogel interior insulation blanket.

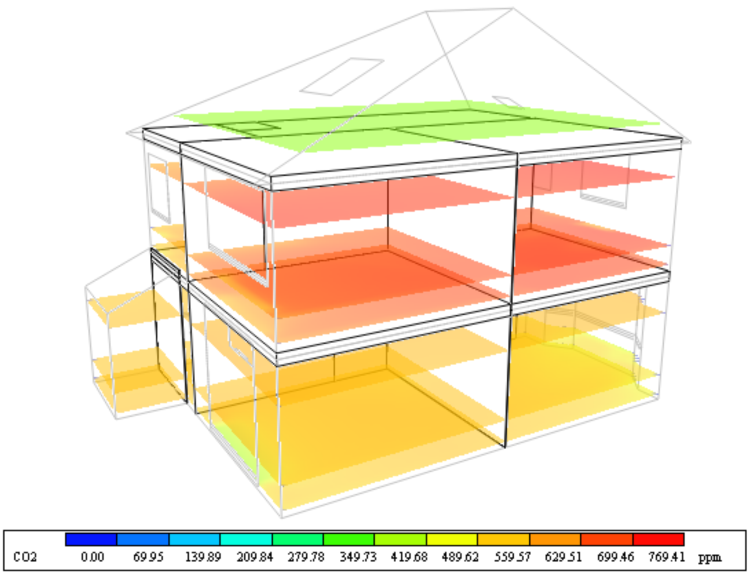


Figure 23 Indoor Co2 distribution when using 15mm Silica aerogel interior insulation blanket.

In 30mm thickness, the maximum indoor Co2 is 1288PPM, the minimum Co2 is 417PPM, the maximum $\Delta Co2\ is\ 871PPM$. Figure 24 shows the detailed indoor Co2 distribution when using 30mm Silica aerogel interior insulation blanket.

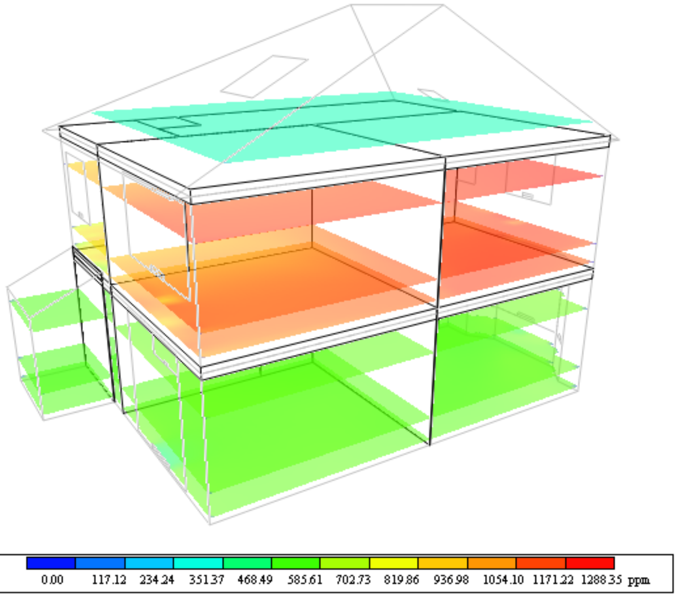


Figure 24 Indoor Co2 distribution when using 30mm Silica aerogel interior insulation blanket.

3.5 PMV when using Silica aerogel interior insulation blanket

The average PMV is -1.7. Figure 25 shows the detailed PMV distribution when using 5mm Silica aerogel interior insulation blanket.

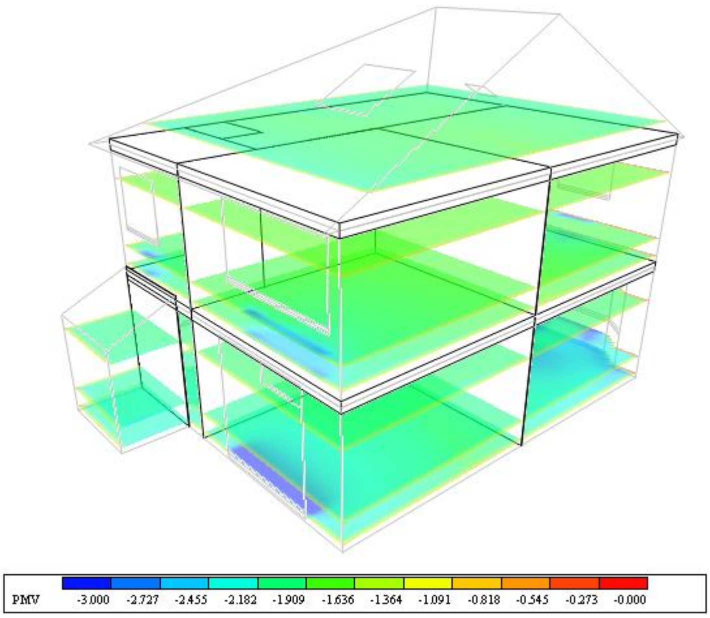


Figure 25 PMV distribution when using 5mm Silica aerogel interior insulation blanket.

The average PMV is -1.5. Figure 26 shows the detailed PMV distribution when using 15mm Silica aerogel interior insulation blanket.

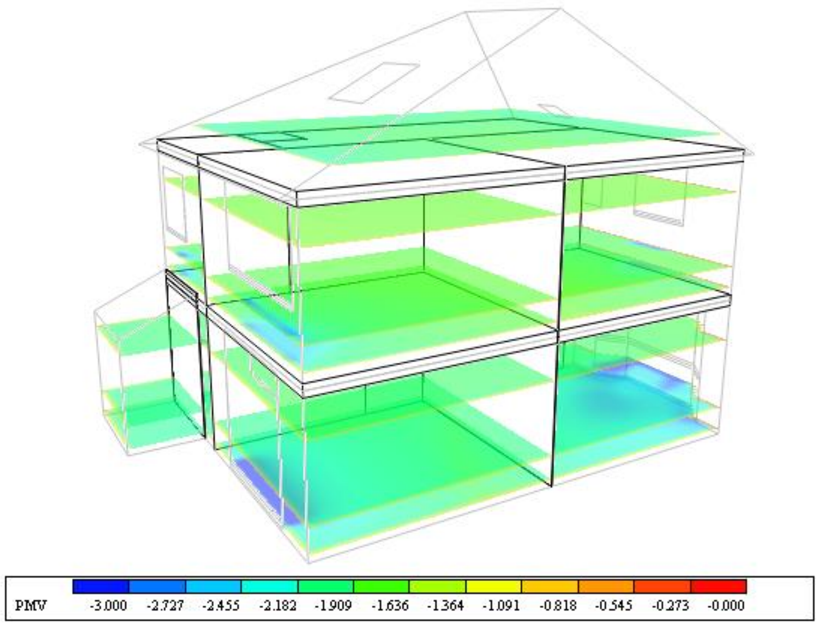


Figure 26PMV distribution when using 15mm Silica aerogel interior insulation blanket.

The average PMV is -1.1. Figure 27 shows the detailed PMV distribution when using 30mm Silica aerogel interior insulation blanket.

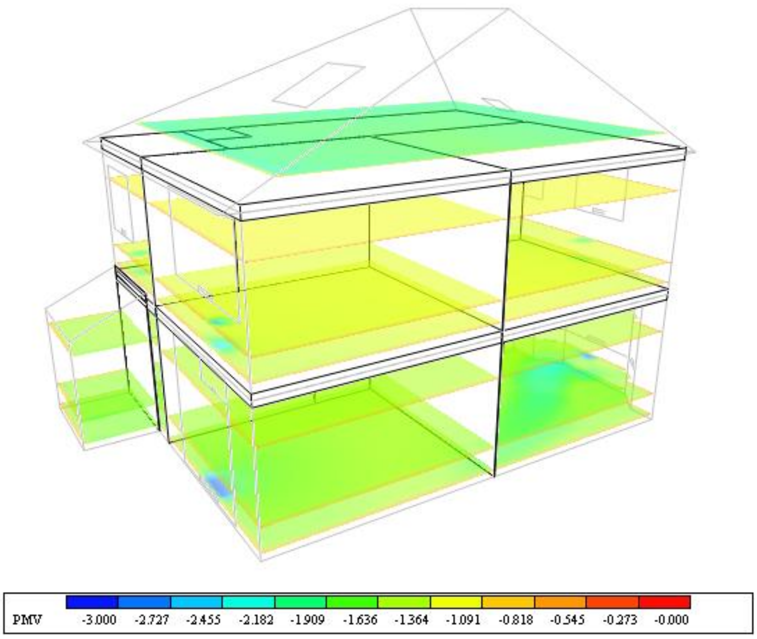
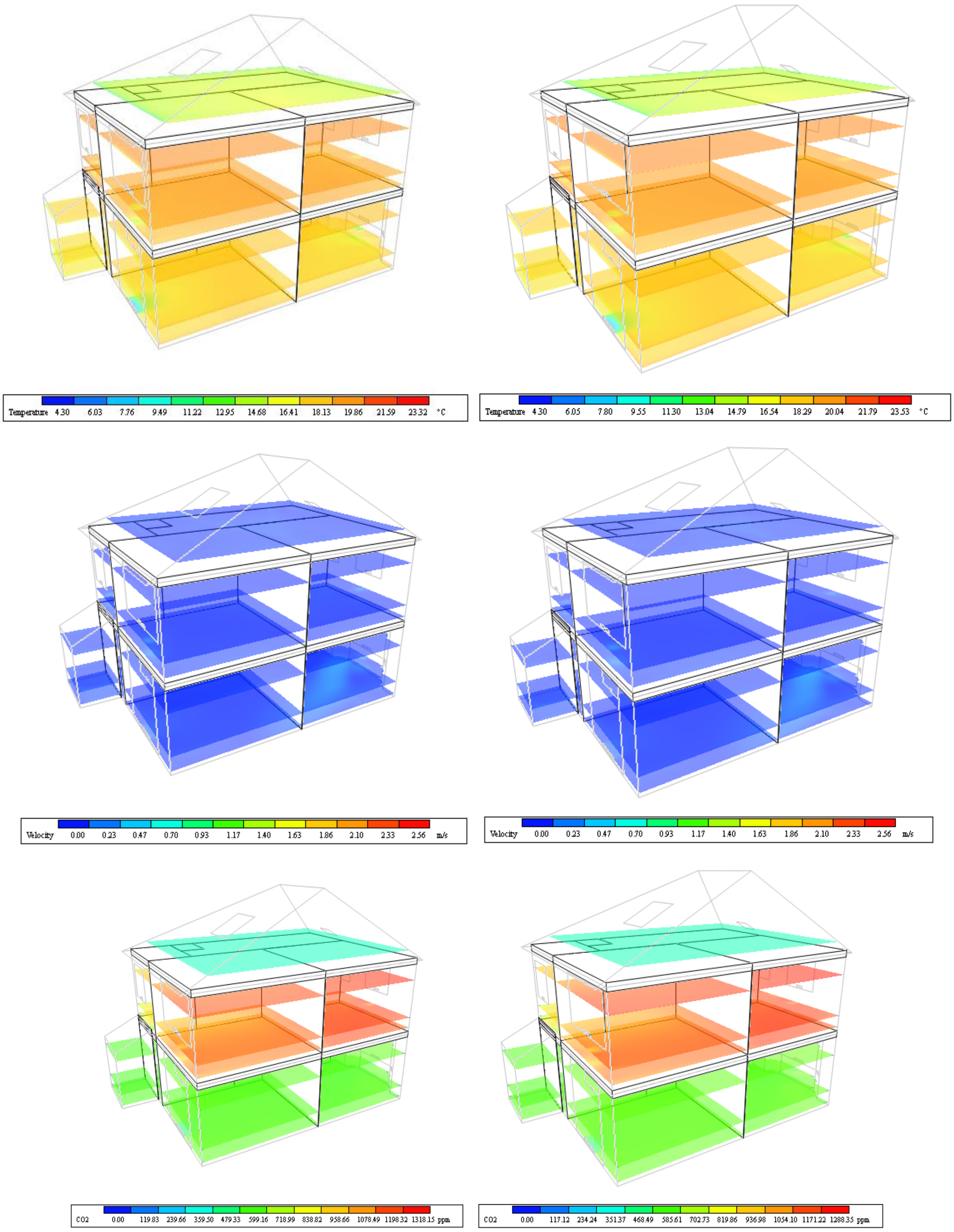


Figure 27 PMV distribution when using 30mm Silica aerogel interior insulation blanket.

4 Interior and exterior insulation of 30mm Silica aerogel insulation blanket

The figure 28 shows the interior and exterior insulation of 30mm Silica aerogel insulation blanket.



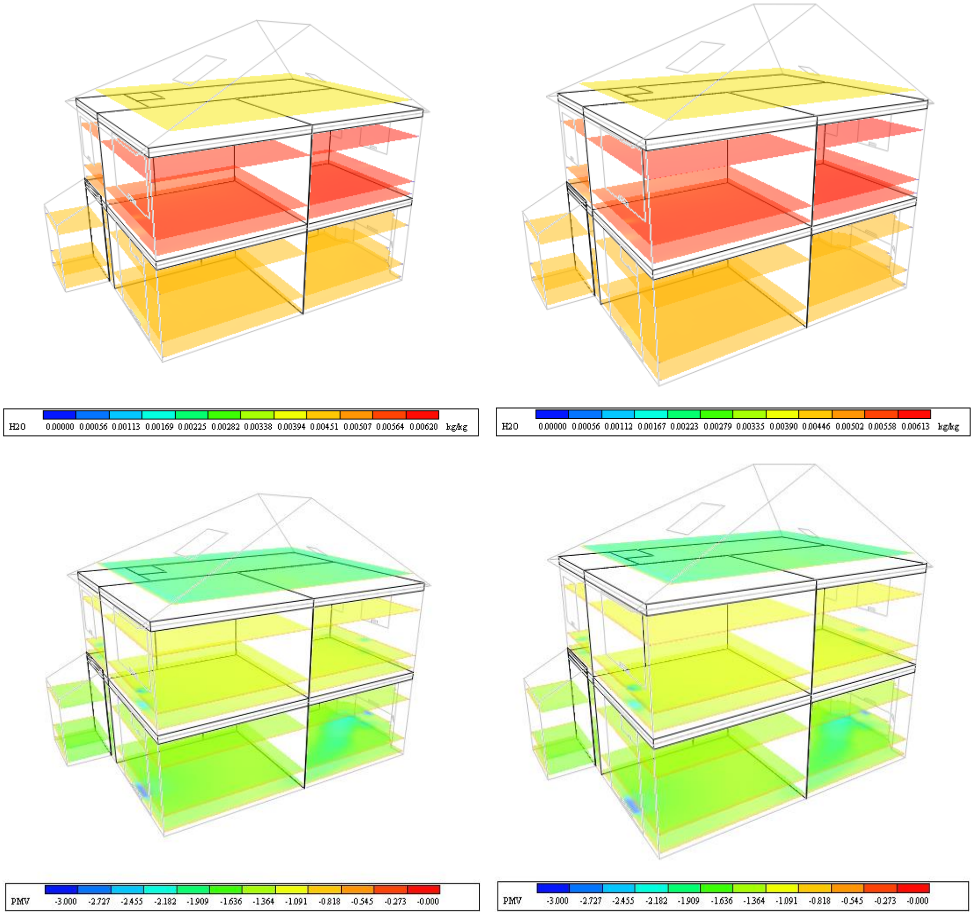


Figure 28 The interior and exterior insulation of 30mm Silica aerogel insulation blanket

4.1 Interior and exterior insulation of 30mm Silica aerogel insulation blanket

The max air temperature for exterior insulation is 0.2℃ higher than that of the interior insulation. The average air temperature for exterior insulation is 0.13℃ higher than that of the interior insulation. The average air temperature for exterior insulation (17.51 ℃) is 0.2℃ higher than that of the interior insulation (17.31 ℃). Besides, the installation position has no impact on the mean air speed.

The CO2 intensity for exterior insulation is 30ppm lower than that of the interior insulation, and the humidity content for exterior insulation is 0.7g/kg lower than that of the interior insulation. The PMV for exterior insulation is 0.2 higher than that of the interior insulation.

4.2 The impact of the Interior insulation of 30mm Silica aerogel insulation blanket on summer

In summer time, when using 30mm Silica aerogel insukatuin blanket, the maximum indoor air temperatue changes to 34.86℃, and the average indoor air temperature 29.19℃. Figure 29 shows the detailed indoor air temperature distribution when using 30mm Silica aerogel interior insulation blanket.

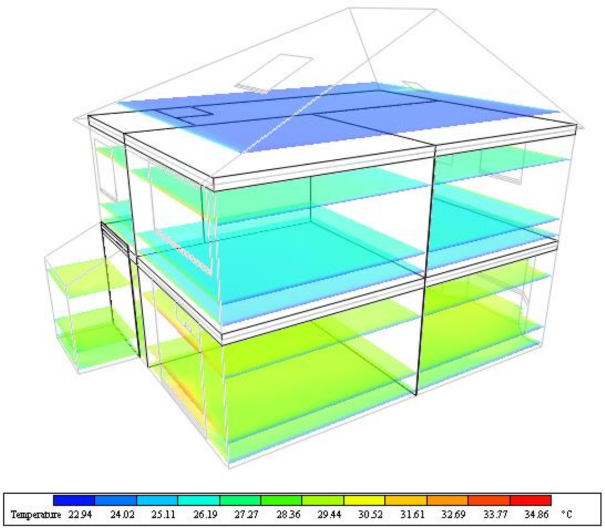


Figure 29 Indoor air temperature distribution when using 30mm Silica aerogel interior insulation blanket.

In summertime, when using 30mm Silica aerogel insulation blanket, the maximum indoor wind speed changes to 34.86℃, and the average indoor air temperatue 29.19℃. Figure 30 shows the detailed indoor wind speed distribution when using 30mm Silica aerogel interior insulation blanket.

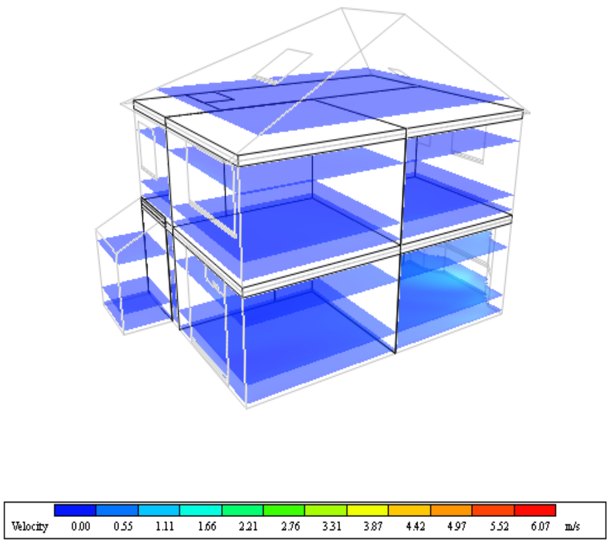


Figure 30 Indoor wind speed distribution when using 30mm Silica aerogel interior insulation blanket In summer time

In summer time, when using 30mm Silica aerogel insukatuin blanket, the maximum Co2 changes to 1500PPM. Figure 31 shows the detailed indoor Co2 distribution when using 30mm Silica aerogel interior insulation blanket.

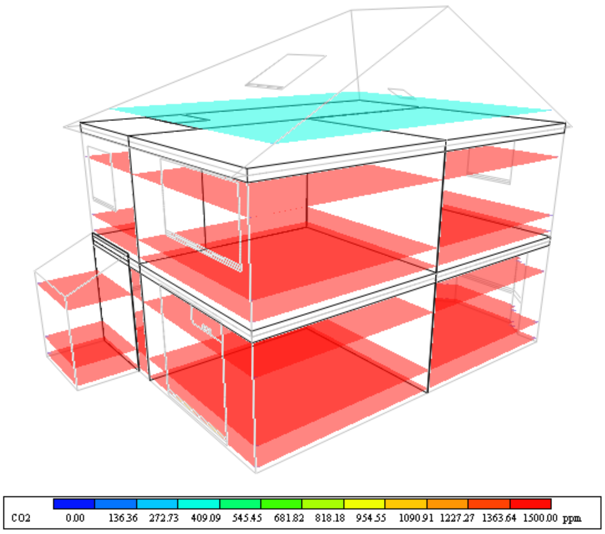


Figure 31 Co2 distribution when using 30mm Silica aerogel interior insulation blanket in summer time.

In summer time, when using 30mm Silica aerogel insukatuin blanket, the maximum indoor air humidity changes to 18.97g/kg. Figure 32 shows the detailed indoor air humidity when using 30mm Silica aerogel interior insulation blanket.

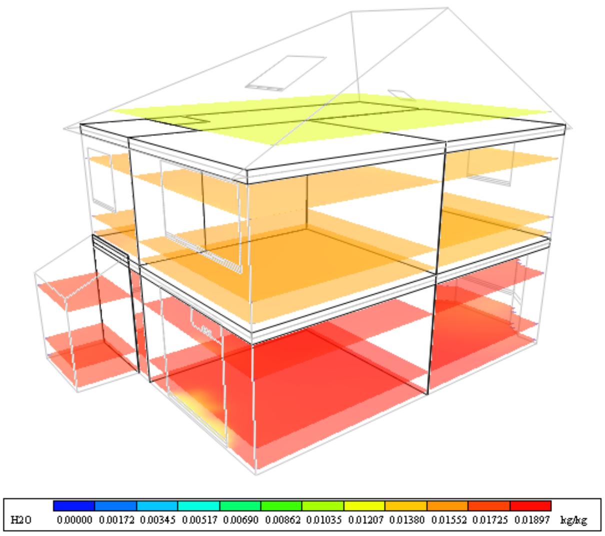


Figure 32 Air humidity when using 30mm Silica aerogel interior insulation blanket in summer time.

In summer time, when using 30mm Silica aerogel insukatuin blanket, the Average PMV changes to 0.2, and the range of PMV change from -1 to 0.5. Figure 33 shows the detailed PMV when using 30mm Silica aerogel interior insulation blanket.

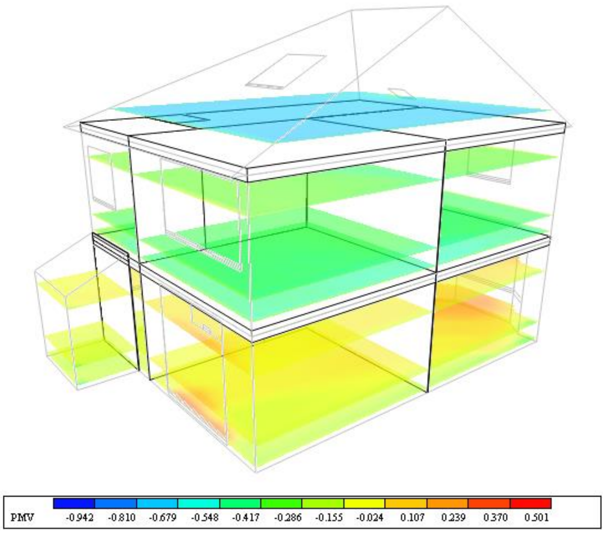


Figure 33 PMV when using 30mm Silica aerogel interior insulation blanket in summer time.

5 PV-vacuum glazing

5.1 Indoor air temperature when using PV-vacuum glazing

In summer time, the maximum indoor air temperature is 25.55℃, and the average indoor air temperature is 25.02 ℃. Figure 34 shows the detailed indoor air temperature when using PV-vacuum glazing in summertime.

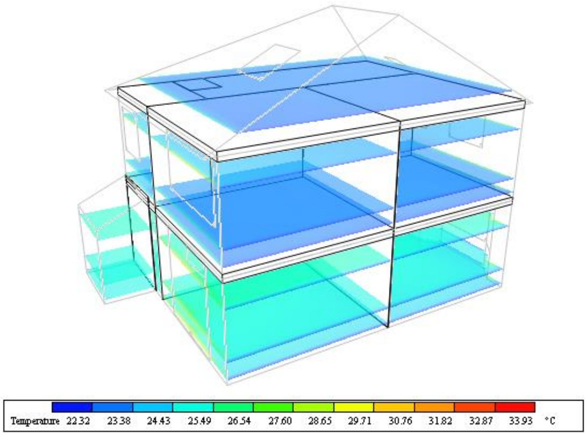


Figure 34 Indoor air temperature when using PV-vacuum glazing in summertime.

In winter time, the maximum indoor air temperature is 17.49℃, and the average indoor air temperature is 17.39 ℃. Figure 35 shows the detailed indoor air temperature when using PV-vacuum glazing in wintertime.

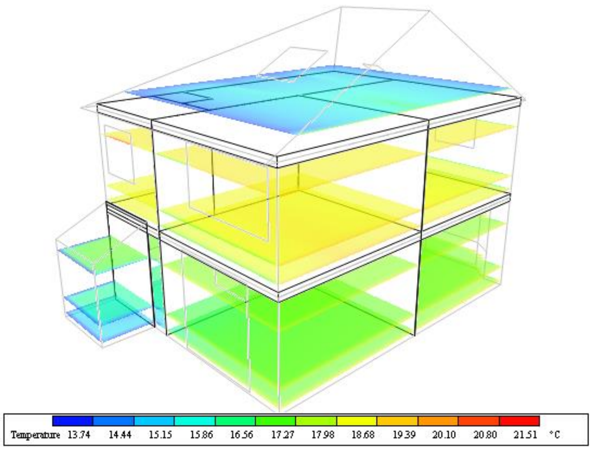


Figure 35 Indoor air temperature when using PV-vacuum glazing in wintertime.

5.2 Indoor air velocity when using PV-vacuum glazing

There is no change of maximun indoor air speed during the summer time and winter time.

the value is 0.09m/s. Figure 36 shows the detailed indoor air speed when using PV-vacuum glazing.

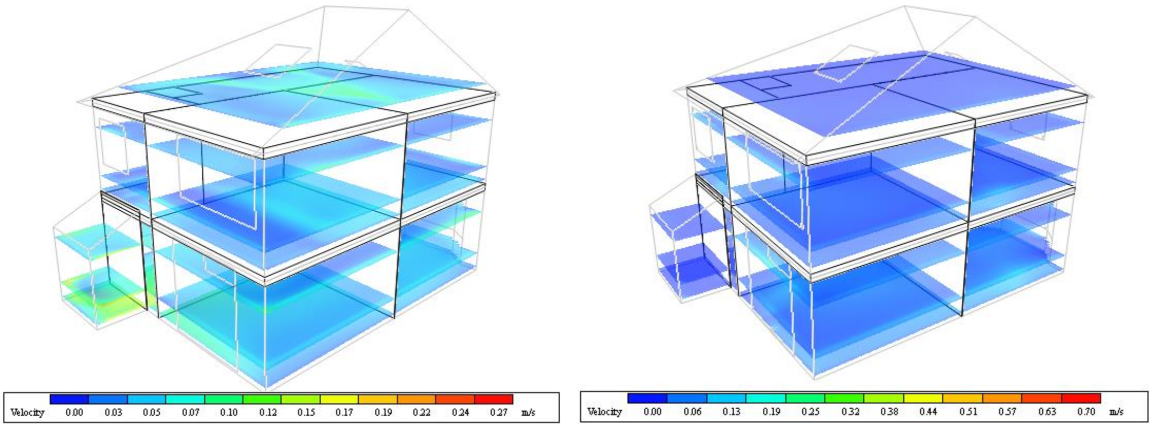


Figure 36 Indoor air speed when using PV-vacuum glazing.

5.3 Average PMV when using PV-vacuum glazing

In summer time, the average PMV is -1.2. Figure 37 shows the detailed PMV distribution when using PV-vacuum glazing in summertime.

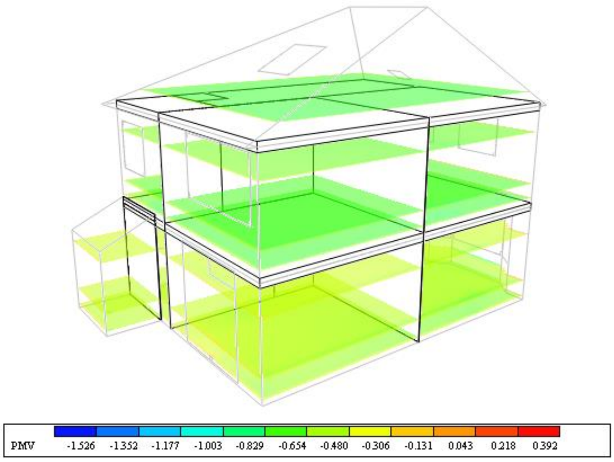


Figure 37 PMV distribution when using PV-vacuum glazing in summertime.

In winter time, the average PMV is -0.65. Figure 38 shows the detailed PMV distribution when using PV-vacuum glazing.

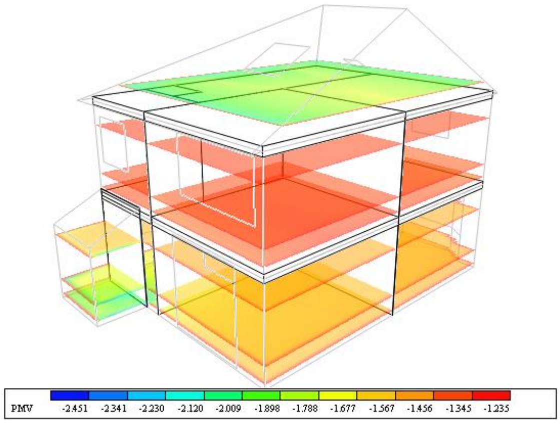


Figure 38 PMV distribution when using PV-vacuum glazing in wintertime.

6 Breathable membrane insulation

In this study, the three difference thicknesses breathable membrane insulation have been adopted to compare the comfort performance.

6.1 Indoor air temperature when using breathable membrane insulation

When using 6mm thickness breathable membrane insulation, the maximum indoor air temperature is 16.98°C, the minimum indoor air temperature is 9.53°C, and the average indoor temperature is 16.06°C. the maximum $\Delta \boldsymbol{T}$ is 7.45°C. Figure 39 shows the detailed indoor air temperature distribution when using 6mm thickness breathable membrane insulation.

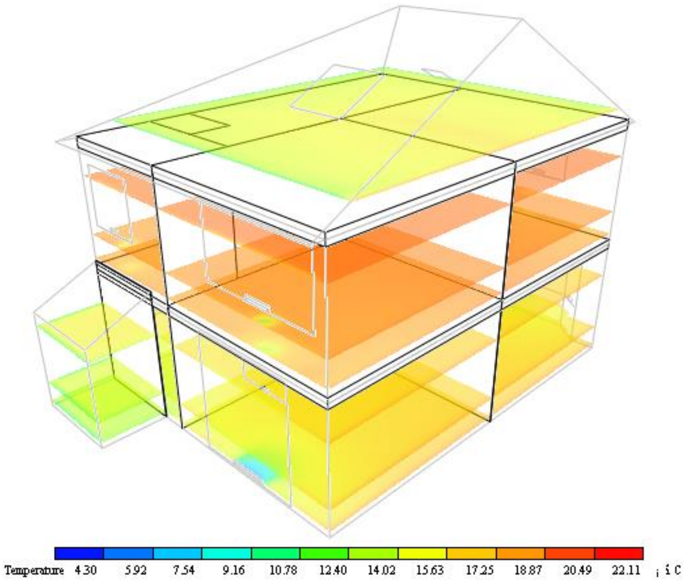


Figure 39 Indoor air temperature distribution when using 6mm thickness breathable membrane insulation

When using 13mm thickness breathable membrane insulation, the maximum indoor air temperature is 18.05°C, the minimum indoor air temperature is 10.5°C, and the average indoor temperature is 17.38°C. the maximum $\Delta \boldsymbol{T}$ is 7.55°C. Figure 40 shows the detailed indoor air temperature distribution when using 13mm thickness breathable membrane insulation.

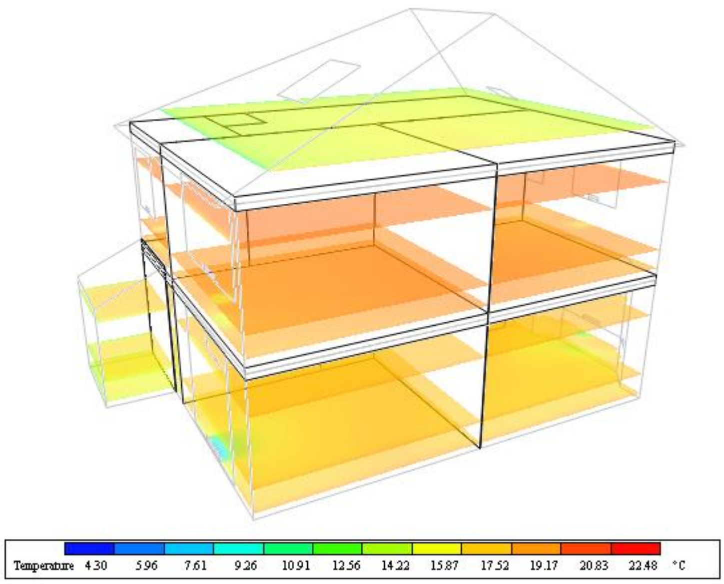


Figure 40 Indoor air temperature distribution when using 13mm thickness breathable membrane insulation

When using 26mm thickness breathable membrane insulation, the maximum indoor air temperature is 18.14℃, the minimum indoor air temperature is 10.48℃, and the average indoor temperature is 17.98℃. the maximum $\Delta\boldsymbol{T}$ is 7.66℃. Figure 41 shows the detailed indoor air temperature distribution when using 26mm thickness breathable membrane insulation.

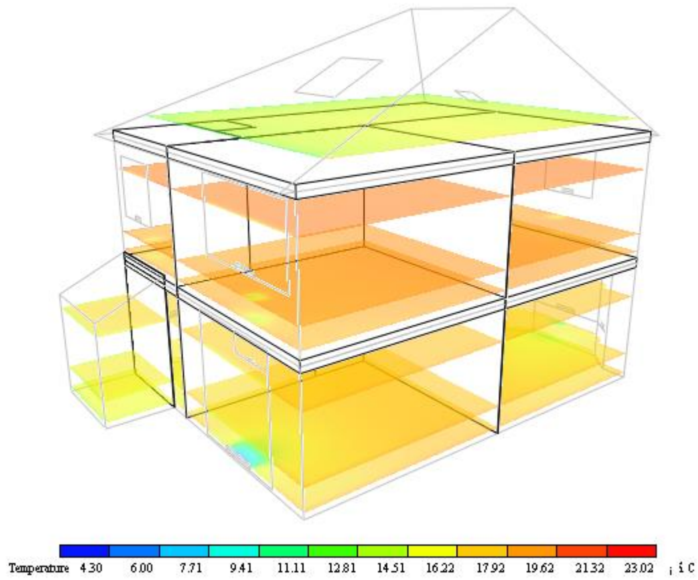


Figure 41 Indoor air temperature distribution when using 26mm thickness breathable membrane insulation

6.2 Indoor moisture content when using breathable membrane insulation

When using 6mm thickness breathable membrane insulation, the maximum indoor air humidity is $5.7g/kg$, Figure 42 shows the detailed indoor air humidity distribution when using 6mm thickness breathable membrane insulation.

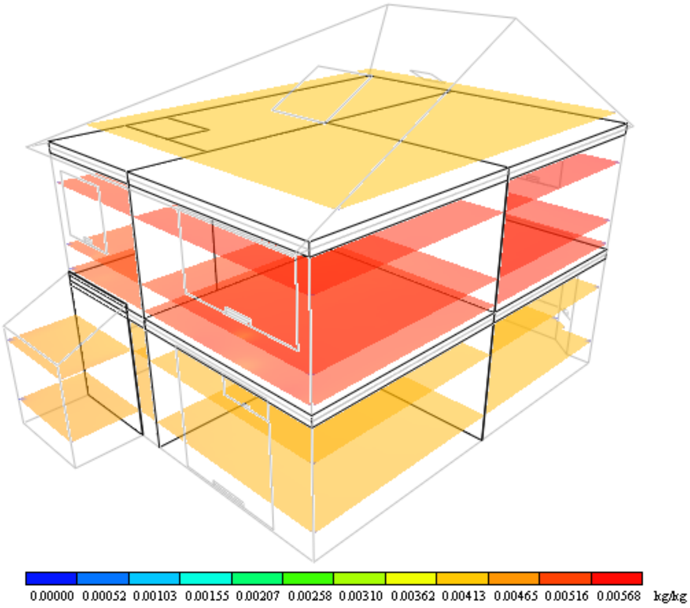


Figure 42 Indoor air humidity distribution when using 6mm thickness breathable membrane insulation

When using 13mm thickness breathable membrane insulation, the maximum indoor air humidity is $6.2g/kg$, Figure 43 shows the detailed indoor air humidity distribution when using 13mm thickness breathable membrane insulation.

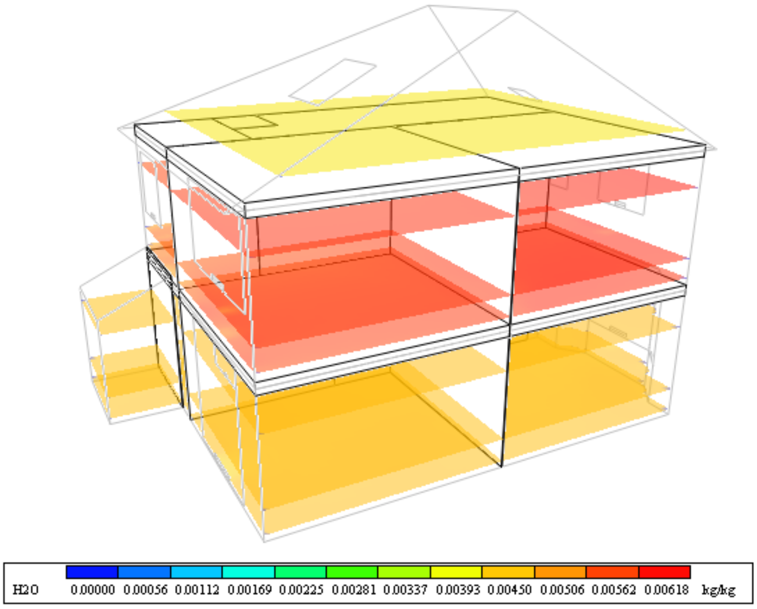


Figure 43 Indoor air humidity distribution when using 13mm thickness breathable membrane insulation

When using 26mm thickness breathable membrane insulation, the maximum indoor air humidity is $6.0g/kg$, Figure 44 shows the detailed indoor air humidity distribution when using 26mm thickness breathable membrane insulation.

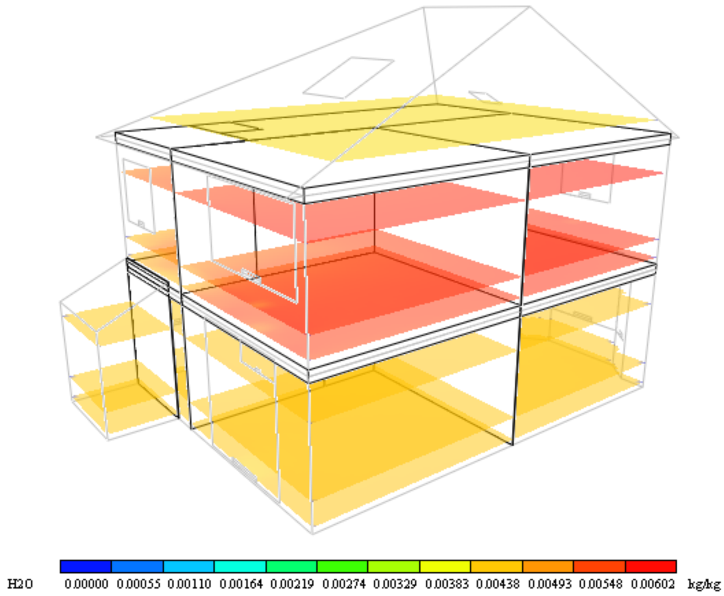


Figure 44 Indoor air humidity distribution when using 26mm thickness breathable membrane insulation.

6.3 Co2 distribution when using breathable membrane insulation

When using 6mm thickness breathable membrane insulation, the maximum indoor Co2 is 1081PPM. Figure 45 shows the detailed indoor air humidity distribution when using 6mm thickness breathable membrane insulation.

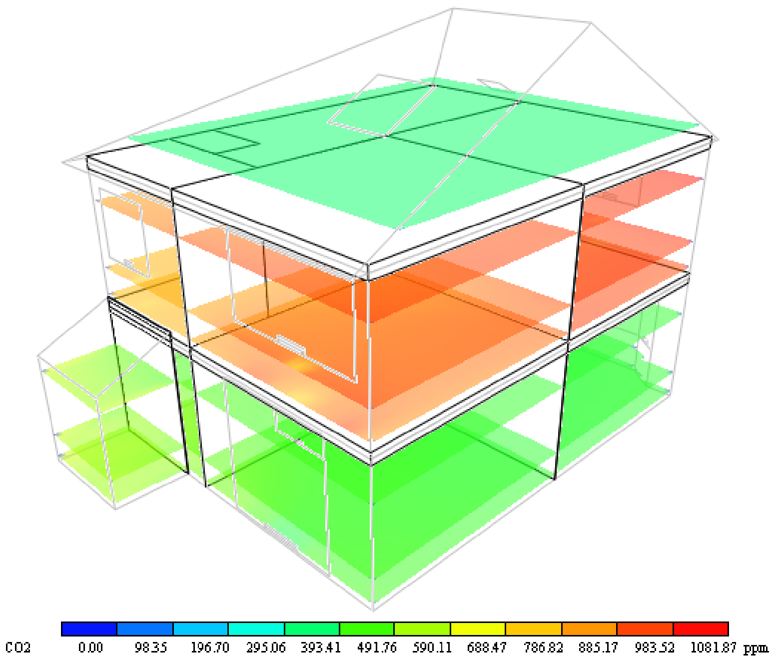


Figure 45 Indoor air humidity distribution when using 6mm thickness breathable membrane insulation.

When using 13mm thickness breathable membrane insulation, the maximum indoor Co2 is 1309PPM. Figure 46 shows the detailed indoor air humidity distribution when using 13mm thickness breathable membrane insulation.

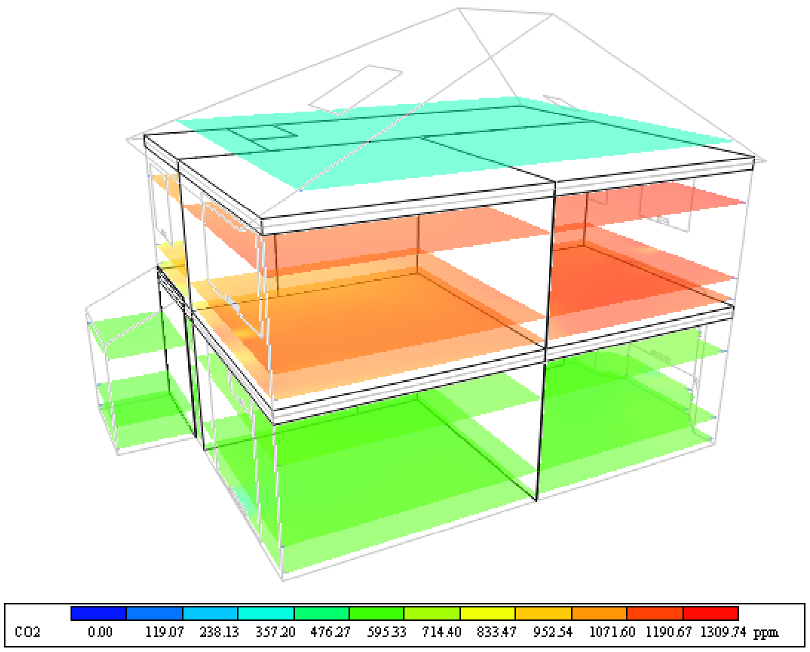


Figure 46 Indoor air humidity distribution when using 13mm thickness breathable membrane insulation

When using 26mm thickness breathable membrane insulation, the maximum indoor Co2 is 1238PPM. Figure 46 shows the detailed indoor air humidity distribution when using 26mm thickness breathable membrane insulation.

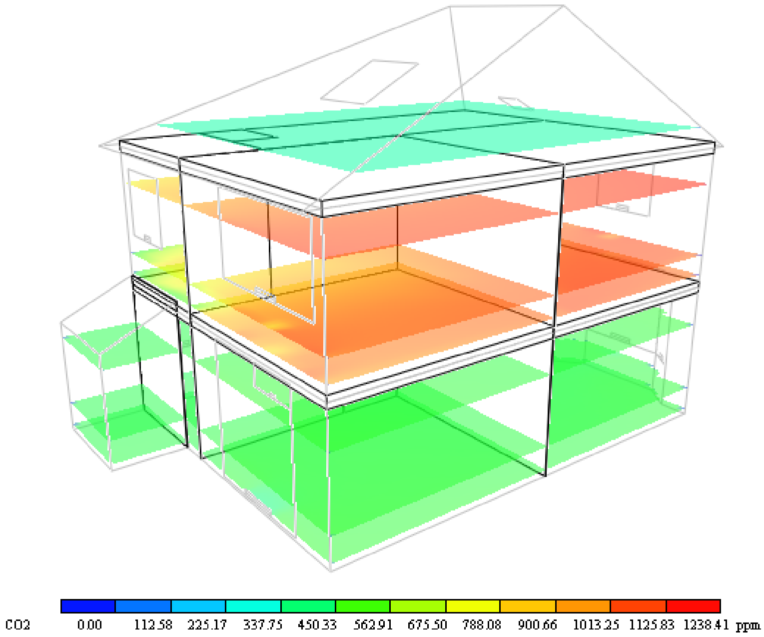


Figure 47 Indoor air humidity distribution when using 26mm thickness breathable membrane insulation.

6.4 PMV when using breathable membrane insulation

When using 6mm thickness breathable membrane insulation, the maximum Average PMV is -1.3. Figure 48 shows the detailed indoor air humidity distribution when using 6mm thickness breathable membrane insulation.

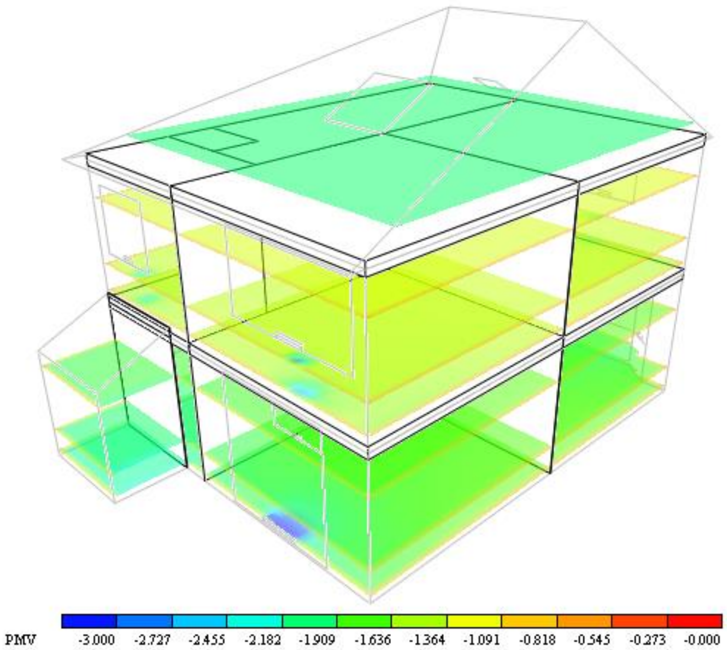


Figure 48 Indoor air humidity distribution when using 6mm thickness breathable membrane insulation.

When using 13mm thickness breathable membrane insulation, the maximum Average PMV is -1.2. Figure 49 shows the detailed indoor air humidity distribution when using 13mm thickness breathable membrane insulation.

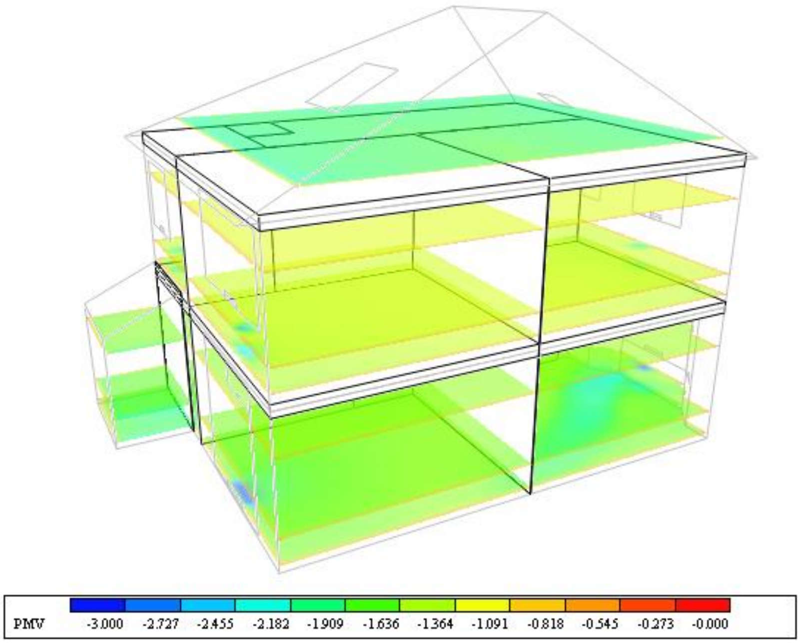


Figure 49 Indoor air humidity distribution when using 13mm thickness breathable membrane insulation

When using 26mm thickness breathable membrane insulation, the maximum Average PMV is -1.1. Figure 50 shows the detailed indoor air humidity distribution when using 26mm thickness breathable membrane insulation.

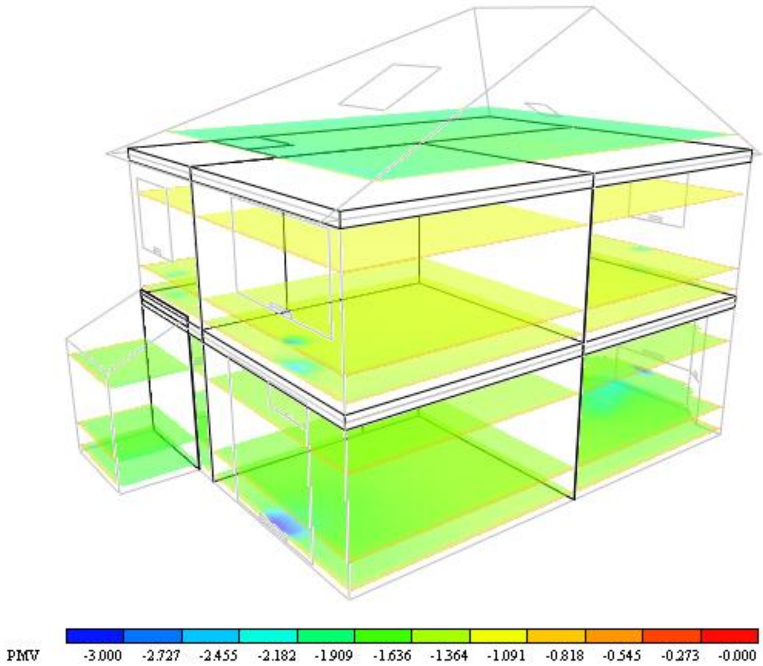


Figure 50 Indoor air humidity distribution when using 26mm thickness breathable membrane insulation.

Conclusions

In this task, the development of indoor air comfort assessment systems has been completed. Optimisation and functional tests with materials are necessary as part of work package 4 previously to the demo site works phase. In this deliverable, the comfort criteria of indoor air temperature, moisture content, indoor air speed, CO_2 distribution, PMV index have been detailed. The different insulation materials and technologies of the project have been explained. In addition, the way of installing the equipment, recommendations and solutions to potential problems have been explained. It is important to note that although these developments are considered of great interest in different types of technologies, on-site measurements are necessary to validate the models in the project.

References

1. Ioannou, A. and L. Itard, *In-situ and real time measurements of thermal comfort and its determinants in thirty residential dwellings in the Netherlands.* Energy and Buildings, 2017. **139**: p. 487-505.
2. *Ergonomics of the thermal environment*, in *Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria*. 2005: ISO.
3. *Standard 55-2013 -- Thermal Environmental Conditions for Human Occupancy*. 2013, ANSI/ASHRAE.