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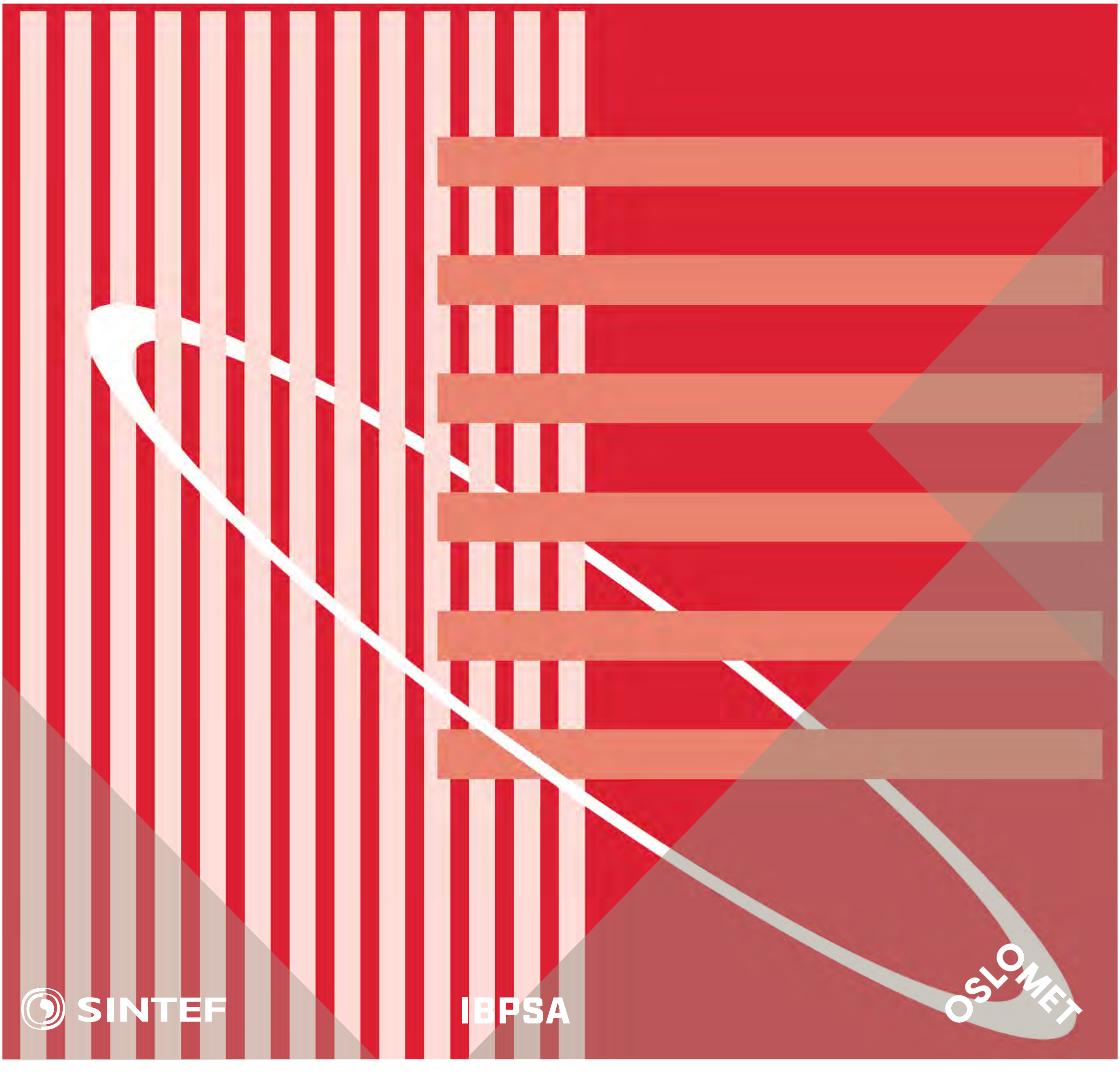
Selected papers



SINTEF Proceedings

Editors:
Laurent Georges, Matthias Haase, Vojislav Novakovic and Peter G. Schild

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CFD Simulation Delivered as SaaS for Building and HVAC Design Testing

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Abstract

This paper discusses the application of cloud-based simulation in the early stages of an HVAC and building design process. Its goal is to show the benefits of the technology through a thermal comfort case study. The simulation was run in a standard web browser, using the cloud-based simulation platform, SimScale. Its results demonstrate the value that SaaS-based simulation has in the architecture, engineering, and construction (AEC) industry.

Introduction

With increasingly high demands for indoor air quality, thermal comfort, and energy efficiency, engineers and architects have a multitude of factors to account for in the building design process. Furthermore, in complying with industry standards, such as ASHRAE 55 [1], ISO 7730 [2], and EN 16798-1:2019 [3], all should be assessed long before construction.

Facilitated by the emergence of cloud computing, computer-aided engineering (CAE) technology is now being delivered by different providers in the form of SaaS solutions. This increases the technology's accessibility and ease of use. Online CAE or engineering simulation has become part of the design testing process, as engineers virtually test indoor climates, measure air quality, ensure thermal comfort, and assess energy efficiency in industrial, residential, and commercial buildings.

This paper will illustrate how a particular type of simulation, computational fluid dynamics (CFD), can be used to understand how thermal comfort is impacted in different design scenarios. The research assesses the capability and value of CFD simulation for preliminary design studies and how it might impact the design of high-performance buildings.

The investigation is supported by a case study that simulates a multi-storey residential building, which was tested with the goal of achieving excellent thermal comfort and energy efficiency.

CFD Simulation and the Emergence of SaaS Solutions

Today, around 1 out of 20 engineers who could benefit from simulation in their product development process have access to simulation tools. The low numbers are tied to large upfront hardware and software investments and steep learning curves.

The expertise that users need in order to operate most simulation software packages is significant. Consequently, proving the added value of traditional simulation tools might take several months. That is where the so-called on-demand software model, more commonly known as "SaaS", comes into play.

SaaS stands for "Software as a service" and is a cost-effective and simple concept. Instead of purchasing a license for a software package—as is the standard for traditional tools—users can rent a product (usually via a monthly or yearly subscription). In SimScale's case, for example, which is a SaaS application for engineering simulation, the platform is hosted on Amazon Web Services (AWS).

Through leveraging high-performance computing (HPC), rather than classical local and on-site hardware, one can scale the number of processing units for a specific problem to both drastically reduce the simulation time as well as parallelise different simulations to help engineers make design decisions.

It is also necessary to have a way to visualize results, which is decoupled from the hardware and allows engineers and designers to make decisions in real-time.

Through the democratization of CAE, there is now a broader range of professionals using simulation, from hobbyists to simulation experts. This democratization has made simulation accessible to a far wider audience than in the days of traditional CFD.

One thing stays the same, however; that is the process of how CFD works "behind the scenes".

1. Creating the CAD model
2. Assigning known inputs
3. Solving/Simulating
4. Post-processing (where the results are visualized)

Often, based on the simulation results, the CAD model is then altered and the design is improved, forming an iterative design process.
For the largest impact, simulation should be utilised in the concept and design phase of a product development cycle.

SaaS solutions fill this growing need for on-demand CFD simulation capabilities by leveraging the performance as well as scalability of HPC systems and eliminating high upfront costs and software licensing. For solutions like SimScale, everything is compactly embedded into a web browser to run sophisticated simulations without compromising on simulation performance or security.

Challenges in Building Design and HVAC Design

Along with the standard concerns for structural integrity, aesthetics, and wind effects, every design project has to meet certain requirements. Residential and commercial buildings need to ensure proper thermal comfort while optimizing for energy consumption, hospitals require high standards of indoor air quality and very specific airflow patterns, factories need measures for contaminant control and underground parking lots must be prepared for fire safety and smoke management.
All of these projects and their challenges have one thing in common; they rely on a well-designed heating, ventilation and air conditioning (HVAC) system.

The process of planning the HVAC system for a building takes into account multiple factors; from the macro, such as the building's position, wind exposure or entrance locations to micro, such as positioning of supplies and returns, windows, heaters, type of insulation, room dimensions, the capacity of the HVAC system, as well as the number of occupants or even positioning of furniture.

All of these elements should be considered in the design phase, and this cannot be done without a proper testing procedure. While standard calculations and data do part of the work, they are often insufficient in assessing a building's performance, especially when regulations need to be met.

Case Study: CFD Analysis of a Multi-Storey Residential Building

One of the main tasks for an HVAC engineer is to design a highly energy efficient system that guarantees indoor air quality and thermal comfort that ensures the safety and wellbeing of its occupants. This is no easy process as a large number of variables need to be taken into consideration. Among these factors are the building materials and layout, the number of occupants, the sources of heat and/or the supply/extract of air to name a few. There are multiple ways an HVAC engineer can tackle the challenge that this task comes with. One effective solution, when dealing with large and complex systems, comes through the use of CFD simulation as a numerical prediction tool. CFD allows the engineer to gain insights into the performance of the HVAC design.
In this project, created online with SimScale, a three-story residential building was simulated in order to validate the effectiveness of the HVAC system, the

indoor air quality, and the thermal comfort in typical summer and winter conditions.

As per ASHRAE 55, the thermal comfort of humans can be determined with two variables; the predicted mean vote (PMV) and the predicted percentage dissatisfied (PPD). ASHRAE 55 states that the PMV is "an index that determines the mean value of votes of a group of occupants on a seven-point thermal sensation scale". The different thermal sensations are shown in the legend below.

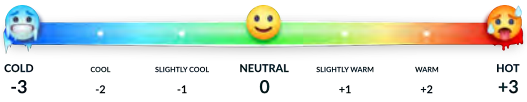

Figure 1: PMV seven-point thermal sensation scale

The PMV value uses six different factors;

1. The predicted occupant metabolic rate
2. Clothing insulation
3. Relative humidity
4. Airspeed
5. Air temperature
6. Mean radiant temperature

In addition to the PMV, the PPD shows the likeliness of local discomfort by the occupants. Amongst the main factors that adversely impact the comfort of occupants are, on one end of the spectrum, too much air movement (this can feel like strong drafts) and on the other end, too little airflow (feels like warm, stale air). In the simulated scenario, all the factors described above will be taken into consideration and PMV will be used to assess thermal comfort.

Model of the Building and Its Environment

The CAD model to be simulated is a three-story apartment building in the city of Munich, with one apartment at each level. The ground floor is made of a 46m^2 apartment and a 12.6m^2 office, the first floor apartment is 58.5 m^2 with a TV room, and on the second floor, there is a 55m^2 apartment with a 3.2m^2 balcony. Below the office floor, there is a garage, which is not included in the CAD model. This section is assumed as an unheated space. There is a hallway on the north side of the building. This part is also not included in the CAD model. In each apartment, two occupants are represented, along with furniture, kitchen countertops, wardrobes, tables, and chairs. In the office, one person is modeled, also with simplified furniture shapes. Supplies and extracts are included and without any of the associated duct work. The level of detail of such a model is minimised to ensure a reasonable computational time while maintaining a good level of accuracy.

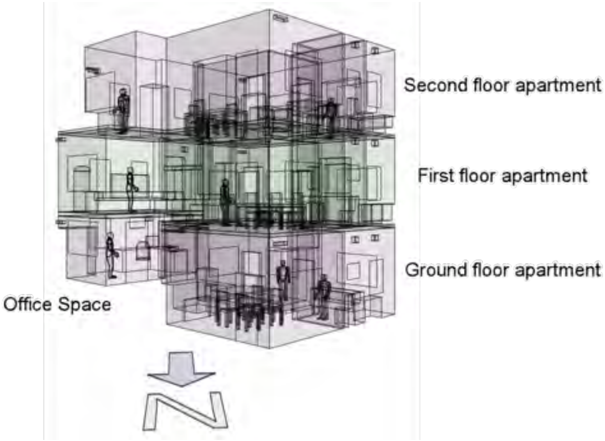

Figure 2: Model of the multi-storey residential building tested in this project

The analysis includes airflow distribution throughout the three apartments and the office. The concrete slabs between the apartments would allow the heat to be transferred through thermal conduction (this model is assuming there are no air gaps or thermal bridging).

Both summer (34°C) and winter (-16°C) scenarios will be considered, with an ambient humidity of 50%.

Direct Normal Irradiance (DNI) for summer and winter seasons are selected based on the coldest and warmest days of the seasons, although both were simulated around midday so the winter scenario is not worst-case.

Within the specified time range, average DNI loads for winter and summer seasons are calculated as 168W/m^2 and 417 W/m^2 respectively. The solar load is added only on the windows facing South-East and

South-West. Only 75% of the DNI is assumed to pass through the windows, to account for reflectivity and the frames.

All heat transfer coefficients and conductance used in this project have been determined according to EN ISO 6946 [4] and EN ISO 10077 [5]. An external heat transfer coefficient of 25 W/(K.m²) is applied on all external walls, doors, and windows. The floor of the building is assigned a high heat transfer coefficient with the ground at 4.5°C for winter and 29.25°C for summer.

According to ISO 6946, an unheated space can be considered as an additional layer with a specific thermal resistance. The transfer coefficient between the office space and garage ceiling is applied as 4.21 W/(K.m²). The apartment entrances are connected to an unheated hallway, therefore a heat transfer coefficient of 2.08 W/(K.m²) is applied to doors and hallway walls. The heat transfer between the air and internal walls is calculated by the solver, based on the local air velocity and temperature.

The apartment block is considered to be equipped with highly insulative components. This project uses thermal conductance as a measure of the thermal insulation. This measure is described in the EN ISO 6946 and EN ISO 10077 standards as the rate of heat transfer through a material. This is usually a composite and the value represents the real-world performance of the materials.

In this project, the thermal conductance through the frame and sash of door and windows was omitted for simplification purposes. The following table shows the conductance values of the building components.

Component	Thermal conductance (W/(K.m²))
Walls	0.32
Double Glazed Windows	2.2
Door	2.55
Roof	0.13
Office Floor (above garage)	0.13
Floor	0.13

Table 1: Typical thermal conductance values [6] [7]

Indoor Air Quality

With any modern building, indoor air quality (IAQ) is of huge importance. This focuses on Ventilation Effectiveness (pollutants, CO2 and other particulates) and Air Change Effectiveness (age of air and fresh air rates).

In this project, to fully control thermal comfort, the constant renewal of air is guaranteed through continuous mechanical ventilation. The outdoor air supplied to the rooms is distributed through hidden ductwork.

Winter Heating Strategy

For the winter scenario, the heating strategy utilizes radiators placed throughout the rooms of the apartments. These devices are usually placed under windows. The windows' thermal transmittance is higher than the walls' and therefore their surfaces would generally be colder. By placing the heaters directly under the windows, the hot air generated would rise and act as an air shield, preventing the cold air from penetrating further towards the center of the rooms.

The power required for the radiators to maintain an average temperature of 21°C was estimated with a hand calculation. This gives a good starting point for a CFD calculation. While the details of the calculations are not presented in this study, the results for the heating requirements for each apartment and office are shown in the table below.

Level	Heating Requirement (W)
Office	105
Ground Floor	431
First Floor	745
Second Floor	702

Table 2: Heating requirement for each floor to reach an average of 21°C – simple hand calculation

It should be noted that the thermal mass of the building has not been considered, nor was any thermal bridging; this is merely a starting point.

For the winter scenario, the total ventilation rate Q_{tot}, per apartment is specified in Table 4.1b of the ASHRAE 62.2 [8] standard. For the 47.3m^2, 60.4m^{2,} and 58m^2 apartment units occupied by two people, the standard recommends a 21 l/s total ventilation rate.

As there are three extraction units per apartment, the baseline design will equally distribute the outdoor air rate at 7 l/s (or 8.3g/s) among these inlets.

The outdoor air rate V_{bz} for the office falls under the ASHRAE 62.1 [8] standard calculation since it is not considered a residential space and is determined with the following formula:

$$V_{bz} = R_P \cdot P_z + R_a \cdot A_z$$

With:
V_{bz} = Outdoor air rate (l/s)
A_z = Zone floor area (m^2)
P_z = Zone population
R_p = Outdoor airflow rate required per person (l/s.person)
R_a = Outdoor airflow rate required per unit area (l/s.m²)

For a 12.6m^2 office space occupied by one person,
R_p= 2.5 l/s and R_a =0.3 l/s.m^2
V_{bz} = 6.56 l/s (or 7g/s).

In this design, mechanical ventilation is considered to be operated by a mechanical ventilation heat recovery system (MVHR). This system has been widely used over the last decade in order to maximize the energy efficiency of buildings. With this installation, the outdoor air is heated up by the exhaust air through a heat exchanger before being introduced into the dwellings. High-performance, double-flow controlled mechanical ventilation units can reach up to 93% efficiency, which means that the -16°C outdoor air is heated to around 1°C by the 21°C air that was just extracted. An auxiliary heating unit then raises the temperature to the desired supply temperature. For the purposes of this project, the building is considered airtight, although leakage paths could be modelled.

Summer Cooling Strategy

For the summer scenario, cool air is supplied into the rooms. In this scenario, the ideal internal room temperature is around 24.5°C, as per ASHRAE 55. Inlet air temperature and speeds must be carefully controlled, in order to avoid any condensation inside the ducting, as well as minimising noise or high pressure losses. Finally, flow rate and temperature should be adjusted carefully, controlling the room temperature while keeping the peak velocity below 0.8m/s. This will ensure that the design remains within the targeted thermal comfort (PMV) range.

Thermal Comfort and Predicted Mean Vote (PMV)

As discussed in the first part of this study, PMV is calculated through six parameters; three of these are taken directly from the CFD results (surface temperature, velocity, and air temperature), the others are manually input (metabolic rate, humidity, and clothing coefficient).
The values for clothing coefficient and metabolic rate are provided by ASHRAE 55:

- For the winter scenario, a metabolic rate of 1.2 (cooking/cleaning) and a winter clothing coefficient of 1 (winter indoor clothing) were chosen.
- For the summer scenario, a metabolic rate of 1.2 (cooking/cleaning) and a winter clothing coefficient of 0.6 (trousers, long-sleeve shirt) were chosen.
- A humidity value of 50% was set as input for the calculation of PMV.

Figures 3, 4 and 5 describe the simulation boundary conditions (known input variables) for the winter simulation, including inlet flow rates, temperature, and internal heat loads.

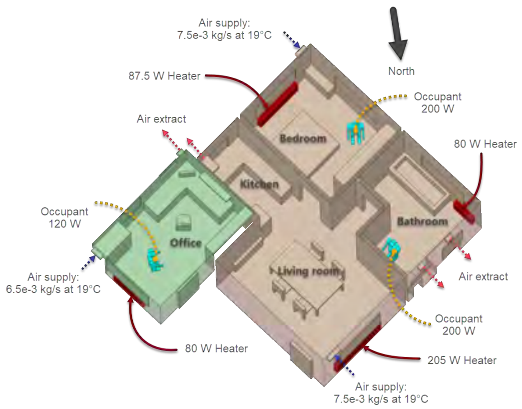

Figure 3: Simulation setup for the ground floor apartment and office

Figure 4: Simulation setup for the first floor apartment

Figure 5: Simulation setup for the second floor apartment

Figures 6, 7 and 8 describe the simulation boundary conditions for the summer simulation, including inlet flow rates, temperature, and internal heat loads.

Figure 6: Simulation setup for the ground floor apartment and office

Figure 7: Simulation setup for the first-floor apartment

Figure 8: Simulation setup for the second-floor apartment

CFD Simulation Results – Winter

The CFD results obtained with SimScale show an accurate heat map throughout the rooms, highlighting hot spots and colder areas. In the pictures below, representing the temperature distribution at 1.5m, one can easily identify hot spots at the heaters and occupants. There are colder zones at the windows and some walls with no heater nearby.

For the ground floor apartment and the office, the temperature remains relatively evenly distributed, with locally low temperatures close to the windows, as expected. The average temperature in the ground-level apartment is 21.3°C and in the office space is 21.1°C. Note that the presence of an occupant in such a small office space (12.6m²) producing 120W of heat, contributes greatly to the heating of the space, the heater in this room producing only 105W.

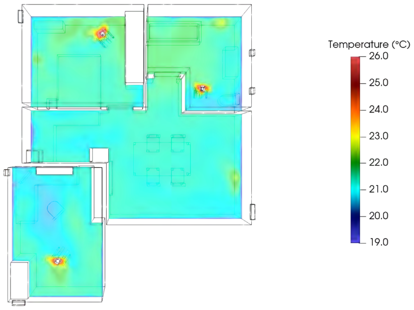

Figure 9: Heat map of the office and ground floor apartment at a height of 1.5m

The first-floor apartment average temperature is 21.7°C and the heat map at 1.5m shows stable throughout the rooms. The warm areas are located at the heaters.

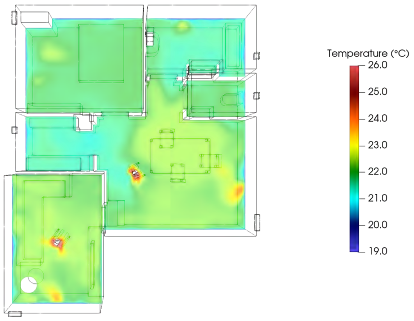

Figure 10: Heat map of the first-floor apartment at a height of 1.5m

The second-floor apartment shows the highest average temperature of all floors, with 21.8°C.

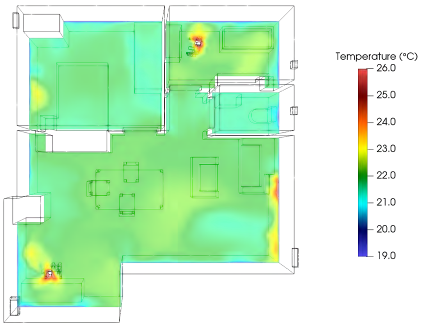

Figure 11: Heat map of the second-floor apartment at a height of 1.5m

The temperature distribution over the entire building reveals the location of the building components with the lower insulation values (or higher conductance); doors and windows are low-temperature faces. It is through these faces that most heat loss occurs and therefore the insulation is essential for energy saving.

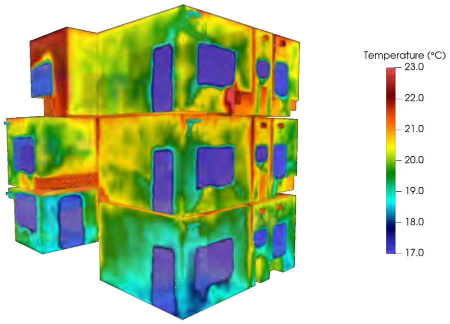

Figure 12: Temperature distribution on the external surfaces

The thermal comfort parameters (PMV) are within an acceptable range as per ASHRAE 55 and so the occupants are likely to feel comfortable. The average temperature in each room is very close to the temperature goal of 21°C (max 0.8°C difference)

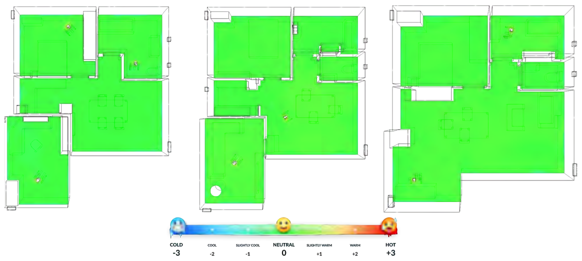

Figure 13: PMV map at a height of 1.5m in each apartment and the office (ground/office, first floor, second floor)

The air velocity results show very low values (below 0.2m/s) throughout the apartments and office, and are considered insignificant to impact PMV results.

The airflow pattern, however, highlights phenomena participating in the thermal comfort results. The heater's hot air shield effect can easily be observed in the pictures below, where the foreground slice shows that the rise of the warm air blocks a cold air pocket against the cold window surfaces. The importance of the phenomenon is clearly visible in the background where cold air is falling downwards and towards the center of the room and over the bed.

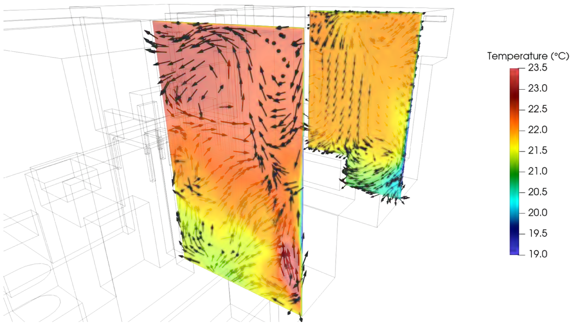

Figure 14: Temperature vertical slices in the second-floor apartment

The thermal comfort results are highly impacted by each heater placement.

CFD Simulation Results – Summer

As with the winter results, heat maps for the summer conditions are shown at 1.5m.

The ground floor apartment is 20.9C on average and the office space is 21.6°C.

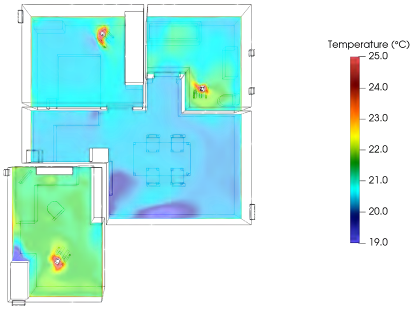

Figure 15: Heat map of the office and ground floor apartment at a height of 1.5m

The first-floor apartment is 21.2°C on average and the 1.5m high heat map, shown below, indicates a very small variance throughout the apartment temperature.

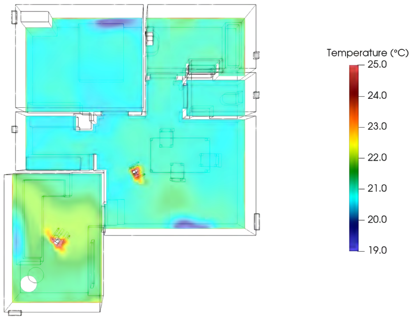

Figure 16: Heat map of the first-floor apartment at a height of 1.5m

The second-floor apartment is 21.4°C on average.

Figure 17 shows that the second-floor apartment bathroom is warmer than the rest of the apartment. This is due to the smaller space and the presence of an occupant contributing an additional 200W.

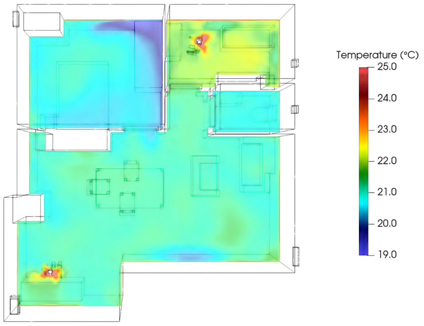

Figure 17: Heat map of the second-floor apartment at a height of 1.5m

On average, the indoor temperature is 21.4°C under summer conditions. The cooling estimation was therefore overestimated since the temperature goal was 24.5°C.

As for the winter scenario the surface temperature results, shown in Figure 18, highlight locations where most heat is transferred between internal and external environments. The windows and doors are warmer on average than the indoor temperature and therefore play a significant role in the apartments' heat gain. Solar radiation also plays a large role in adding heat to the southerly rooms.

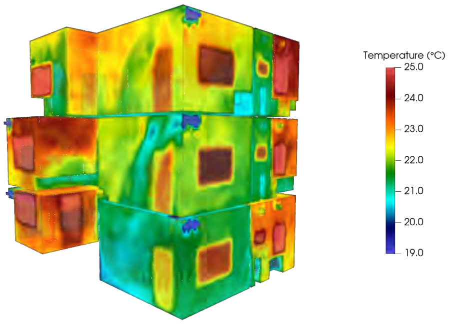

Figure 18: Temperature distribution on the external surfaces

As warm air rises, the air is warmer closer to the ceilings and the upper apartments are warmer overall. The picture below shows a sliced heat map through the row of inlets in the living rooms. Cold air enters the room and falls towards the ground due to its higher density and mild stratification is visible in each room. Visualising the air distribution helps to position the diffusers of the ventilation system appropriately and also to size them in order to ensure the appropriate air velocity and temperature as specified in ASHRAE 55.

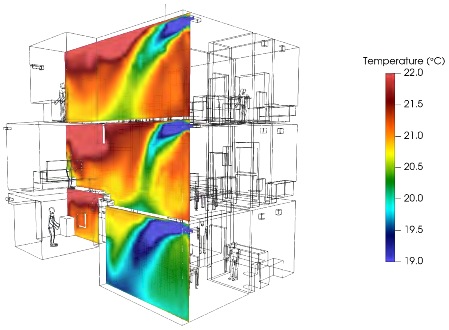

Figure 19: Vertical slice heat map showing the temperature distribution in the living rooms

The thermal comfort results are mainly satisfactory, with PMV values within the recommended range (between -0.5 and 0.5) as per ASHRAE 55. Occupants are expected to feel comfortable in this space.

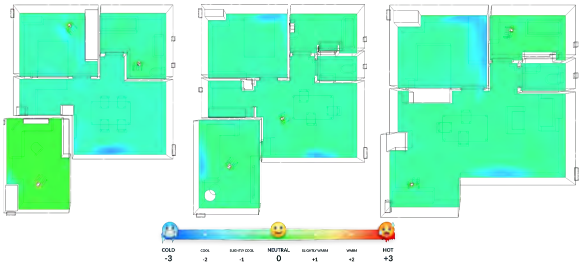

Figure 20: PMV map at a height of 1.5m in the apartments and the office (from left to right, ground/office, first floor, second floor)

Conclusion

When it comes to ensuring thermal comfort, indoor air quality and maximizing energy efficiency, CFD simulation is a convenient tool for HVAC engineers. The visualization of flow distribution can be particularly useful in solving thermal comfort issues. If used early in the design phase, it can deliver valuable information to optimise the HVAC strategy.

Energy calculations can be useful but they are not able to capture the small details. CFD provides additional insights that can significantly impact thermal comfort.

As stated above, in both summer and winter scenarios the thermal comfort is mainly within a satisfactory range and the occupants are expected to feel comfortable in this space. Some regions are outside of the recommended limits, although they are closer to the walls and rarely occupied.

To optimise this design, as the overall air speed is well below the maximum allowable 0.8 m/s, we could look to save energy through a higher supply velocity. This would mean we could spend less energy on cooling the air, which should produce a more efficient system overall. The advantage of using SaaS based CFD is that various experiments can be run in parallel. This means it is possible to assess a range of proposed designs in the time it takes to produce results for one.

References

1. Standard 55-2017 -- Thermal Environmental Conditions for Human Occupancy (ANSI/ASHRAE Approved), https://www.techstreet.com/ashrae/standards/ashrae-55-2017?product_id=1994974
2. ISO 7730:2005 Ergonomics of the thermal environment https://www.iso.org/standard/39155.html
3. EN 16798-1:2019 Energy performance of buildings. Ventilation for buildings. https://shop.bsigroup.com/ProductDetail?pid=000000000030297474
4. ISO 6946:2017, Building components and building elements; Thermal resistance and thermal transmittance; Calculation methods, https://www.iso.org/standard/65708.html
5. EN ISO 10077 Thermal performance of windows, doors and shutters https://www.iso.org/standard/64995.html
6. Designing Buildings Wiki, U-values, https://www.designingbuildings.co.uk/wiki/U-values
7. ENSTO, U-values, http://www2.amk.fi/Ensto/www.amk.fi/opintojaksot/0705016/1204287624126/1240556832300/1240557351157/1240563573560.html
8. Standard 62.1-2019 -- Ventilation for Acceptable Indoor Air Quality (ANSI Approved) https://www.ashrae.org/technical-resources/bookstore/standards-62-1-62-2