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Forging BIM Configurator for HVAC Systems

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Learning Objectives

- Learn how to build an online BIM configurator for a range of applications.
- Learn how to use Revit design automation APIs.
- Learn how to use custom graphics in the Forge Viewer.
- Learn how to create a sketcher for 2D design spaces creation.

Description

The industry is moving from mass production to customized solutions, creating a tremendous increase in the demand for custom BIM (Building Information Modeling) software solutions. However, custom solutions are expensive to develop. With Forge, you can build custom BIM configurators with minimum investment and time. We created a custom simulation app for HVAC professionals to produce a sustainable design. The app simulates the performance of design spaces and HVAC systems configuration in the cloud. The class will demonstrate how to use Forge to create a new user-defined office build space. We will elaborate on how the assembly of complex 3D HVAC system configurations can be made. You will see how Revit design automation APIs can construct an accurate, intelligent model on the server. Attendees will learn these techniques, as well as how to create wide variety of online BIM system configurators such as kitchen design, furniture design, infrastructure design, and others.

Your AU Speakers

Sandip Jadhav
CEO, CCTech (sandip@cctech.co.in)

Sandip is a successful entrepreneur in the CAD/CAE space. He has co-founded CCTech, Zeus Numerix, Adaptive 3D Technologies, LearnCAx, and recently simulationHub, a cloud-based CFD platform. Sandip has led several product teams, conceptualizes design software, and implements web apps in simulation space. Sandip is a passionate software developer and loves to tinker with technology.

Rohit Chavan
Software Development Manager, CCTech (rohit@cctech.co.in)

Rohit is the Software development Manager of the simulationHub CFD cloud platform. Rohit is an agile leader who has helped to build multiple simulations apps for the simulationHub team. He has deep expertise in building scalable, resilient, beautiful web apps using Autodesk Forge, AWS, SWS, and a range of full-stack technologies. He is a scrum advocate to build cross-functional and self-organizing teams to create high-value products. Rohit is a graduate of Computer Science from Pune University.

Praveen Kumar
Product Manager, CCTech (praveen@cctech.co.in)

Praveen is a Product Manager of simulationHub, a flagship CFD platform of CCTech. Praveen has deep expertise in converting real-world problems into accurate computational problems. He has been instrumental in conceptualizing the building simulation apps for the simulationHub team. With more than 13 years of strong domain experience in CFD, he has also developed a flavor for user experience. Praveen holds a Bachelor's degree in Mechanical Engineering and Postgraduate DACFD.

Outline

HVAC - Indoor Air Quality

Indoor Air Quality (IAQ) is the air quality inside buildings as represented by concentrations of air contaminants and thermal conditions that affect our health and comfort.

Thermal comfort is an essential aspect of IAQ in representing human satisfaction, defined as "the condition of mind which expresses satisfaction with the thermal environment" – ASHRAE. It means that a person feels neither too cold nor too warm. Thermal comfort is vital for health and well-being, as well as productivity. A lack of thermal comfort causes stress among building occupants. When the environment is too warm, occupants can feel tired; they will be restless and distracted when too cold.

Environment factors contributing in thermal comfort

About 90% life of an average human being spends in the indoor environment. A significant portion (40%) of the world's energy consumption is in the building's environment. Indoor thermal comfort accounts for 30 to 40% of that energy. Thermal comfort is critical inside office spaces, restaurants, public buildings, including airport, station, movie hall, library, classroom, etc.. Therefore, well-designed building ventilation systems must be installed to optimize energy use while providing satisfaction to the building occupants, without fail.

The environmental factors contributing to thermal comfort include air temperature, humidity, air movement, and thermal radiation. Personal factors include physical activity and clothing. The occupant's physical activity represents the metabolic rate or body heat production level, and the dress represents the insulation.

BIM for HVAC - A growth catalyst

To understand the benefits of BIM to the HVAC industry, we must explore some of the global benefits of BIM and discuss HVAC's direct help. Globally one of the significant advantages of Building Information Modeling is creating an accurate model that is useful throughout the entire life of the building, from initial design through occupancy and operation. Ideally, a BIM would be made in the early stages of the invention, updated as the system is refined and used by the construction team, and refined continuously as the facility constructed. Post-occupancy, the BIM would be used by the owner and owner's maintenance team to improve understanding of building operation and make adaptations, renovations, additions, and alterations to the building faster and less cost than traditional processes. Future benefits may include linking HVAC manufacturers' R&D databases.

HVAC Interdisciplinary Impact

The HVAC industry's work impacts every other design and construction discipline and trade, including the following: architecture, electrical engineering, lighting design, roof and envelope consultation, food service, fire protection, civil engineering, structural engineering, security consultants, acoustic engineering, and others. BIM can benefit these associated and complementary disciplines and trades through precise interdisciplinary coordination using parametric geometric modeling. Autodesk Revit and simulationHub kind of software allow adjustments and fine-tuning of the calculations via changes in the BIM and vice versa, resulting in optimizing the BIM in real-time. The HVAC industry impacts building owners, users, regulatory agencies, legal, finance, operation and maintenance, the environment, and the community. BIM can benefit project participants and these entities through improved multi-discipline collaboration to achieve optimal solutions, interference checking before construction, reduced errors and omissions, automated code reviews, accelerated permitting, and earlier beneficial occupancy, leading to an enhanced return on investment (ROI) for the building owner/developer. Real-time monitoring of a building's temperature, humidity, ventilation, air quality, pressurization, isolation, compartmentation, and occupant location integrated into the BIM benefit everyone.

BIM for Sustainable HVAC

BIM will play a significant role in helping us meet the world's need for sustainable construction and climate protection. HVAC systems are one of the largest users of energy in a building. BIM will allow a design team to better a “reduce and optimize” approach to reaching a client’s and building project’s sustainability and climate protection goals by reducing energy. The most important aspect of providing sustainable high-performance buildings is the attention to detail given to the selection, optimization, and use of materials and components based on whole-building life-cycle assessment.

HVAC Influenced Professionals

Specifically, the HVAC industry benefits from embracing and adopting BIM processes in many ways. The HVAC industry is broad and expanding. Some of the disciplines and trades that fall under the category of HVAC include, but are not limited to:

- HVAC engineers
- HVAC consultant
- HVAC contractors
- HVAC manufacture
- Building scientists
- Energy modelers
- Economics Sustainability and Climate Protection
- Building performance modelers
- Specification writers
- Facility managers
- Commissioning agents
- Test and balance agents
- Building automation integrators
- Researchers and Faculty
- Manufacturers of HVAC components

Thermal Comfort Evaluation

Thermal comfort evaluation of an indoor space needs two major tools at the early design stage - Building Energy Modeling (BEM) and Computational Fluid Dynamics (CFD).

Energy Modelling for HVAC

BES is the replication of building performance using a mathematical model based on fundamental physical principles. Using BES, HVAC designers can calculate the thermal loads in spaces for the sizing of HVAC systems, the sizing of mechanical equipment, and test system control strategies to check the energy usage. BES helps in the early-stage design of an energy-efficient HVAC system.

CFD Simulation for HVAC

In the HVAC system design, space's air distribution is equally important as the energy-efficient system. A designer can achieve the required thermal comfort and indoor air quality level through effective air distribution, which are the critical parameters for HVAC design. BES can only calculate the necessary flow rate in the space based on the thermal load and supply airflow properties, but not the diffusers' placement for adequate air distribution to achieve the thermal comfort level. The designer can use a CFD tool to find these parameters by implementing the BES information as a boundary condition. For the thermal load of a space calculated from BES, a designer can evaluate the thermal comfort level and indoor air quality for different air distribution systems like overhead, underfloor, displacement, etc., and decide on selecting the air distribution with the help of a CFD tool.

Using a CFD tool, an HVAC designer can effectively design a system that will provide the required level of thermal comfort and good quality of air in the space.

Objectives of building performance analysis and appropriate tools

Objective	Simulation Tool
Enclosure thermal behaviours	BES
Energy consumption	BES
HVAC system capacity	BES
Thermal comfort (Air temperature, velocity & humidity)	CFD
Indoor air quality (Contaminant concentrations)	CFD
Air distribution	CFD

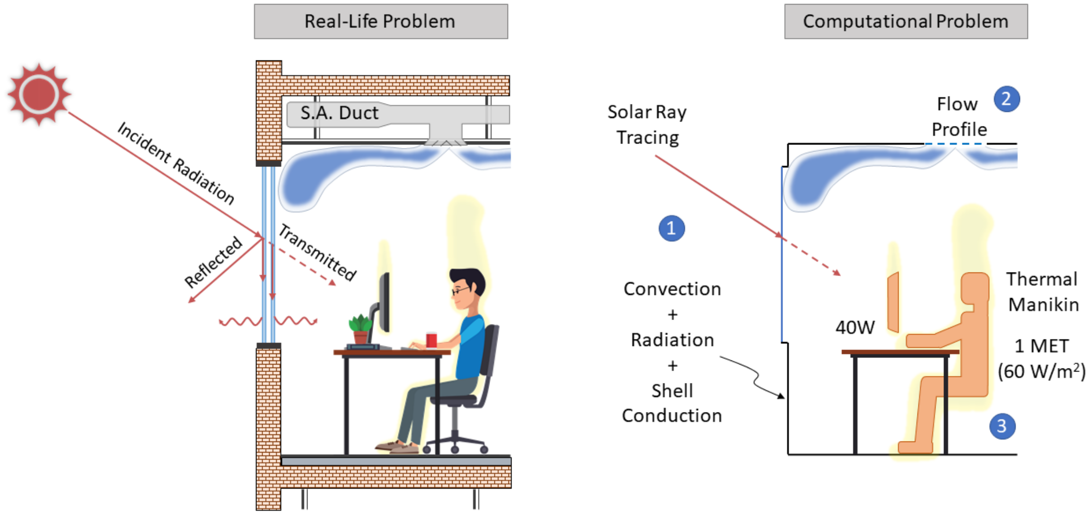
Converting a Real-World Problem into a Computational Problem

The objective of any CFD study is to solve a real-world engineering problem using numerical methods. Converting the real-world problem into a computational problem requires a complete understanding of the physics, challenges in modeling them, and careful planning. The computational domain boundaries should be selected where the information on the flow variables is known or approximated to depict real-life problems. These boundary conditions require a mathematical model to specify the mass, momentum, and energy fluxes into the computational domain.

In building HVAC, let’s look at the physics involved in the heat transfer to/from the indoor conditioned space and how taken into account in the computational problem. For example:

1. In real-life, Heat transfer between the external walls/windows and the surrounding environment takes place using radiation from the sun, convection from wind flowing around buildings, and conduction through the (a solid) material. In the computational problem, only the walls & windows' internal surfaces are combined with external radiation and convection heat-transfer boundary conditions along with shell conduction.

The solar raytracing technique would provide the heat load on different building surfaces depending on the sun's location w.r.t to building orientation, site location, and day |date| time of the year for which one would like to simulate. External emissivity, transmissivity, thermal transmittance 'U' the assembly's value, wall thickness are taken from the material library. Convective heat transfer coefficient and ambient temperature are selected based on the available weather data from the nearest weather station.



Converting real-world problem into computational problem

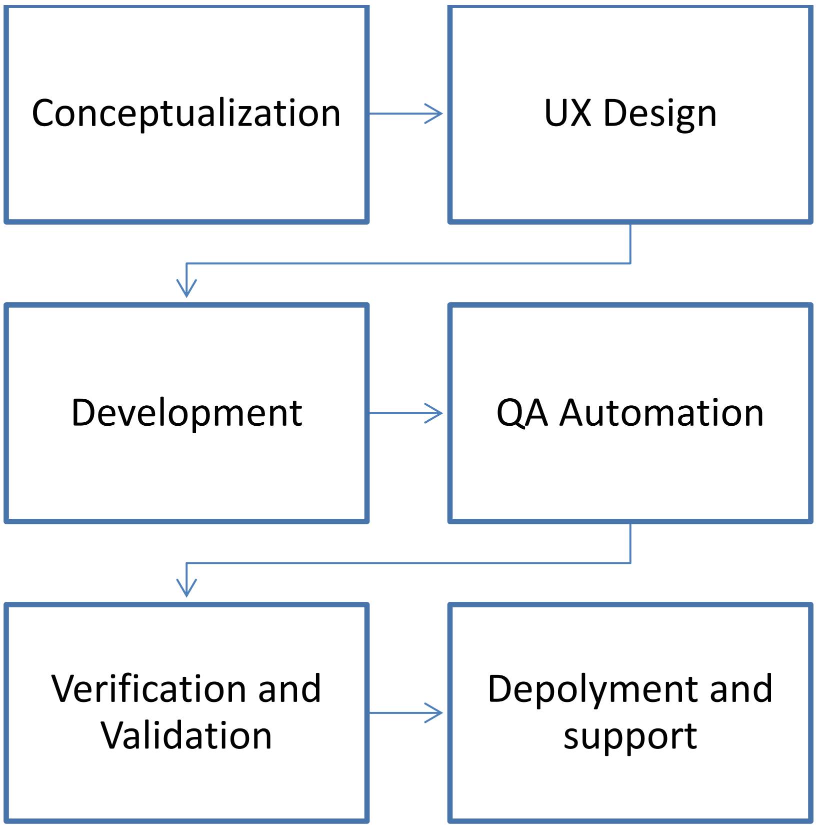
2. In real-life, the conditioned air from AHU units is supplied through the supply air duct above the ceiling and enters the conditioned space via diffusers. The way the conditioned air is distributed in the rooms depends on several factors like the effective flow area, flow angle, flow rate, etc. But including all the AHU, ducts, and diffuser geometry details in the computational domain could be challenging. Instead, a velocity flow profile is a use to depict the flow pattern from diffusers without losing the physics like the Coanda effect when the airflow is near projected to a parallel surface, such as a ceiling.
3. The real-life human occupants represented using standard thermal manikins that are simplified human body forms with the constant heat source to simulate the heat transfer between humans and their thermal environment. ASHRAE has recommendations on the amount of heat for different human activities.

Thinking Behind The App Making

Todays' web application development has inherent characteristics of multi-platform, multi-language, multi-device developed by cross-disciplinary teams. Therefore, we must follow the appropriate processes and software development methodologies.

What is the Process?

Thousands of companies come up with millions of app ideas every year; however, very few realized into an app or a product. Any new software application development needs a considerable amount of investment and resources to be dedicated resources by the organization. Therefore, it is an essential proven process are following to develop a successful app. We have been the following process for creating our apps for several years.
Each block needs critical stakeholders' attention, several strategies, planning meetings with domain experts, and detailed documentation followed by effective implementation.



Process involved in App making

Our subsequent sections cover various details of each block from this diagram.

Conceptualization of the App

Thermal Comfort and Indoor Air Quality analysis are among the most useful methods of evaluating an HVAC design and identifying occupants' thermal perceptions in a building space. CFD is a powerful tool to analyze thermal comfort and dissatisfaction in buildings early at the design phase. But still, only 1 out of 100 designers use CFD simulations to evaluate their HVAC design, and it has not become an integral part of the design process.

A user research study was conducted to understand the real reason behind this situation and understand the requirement to cater to the industry need. Following voices registered through the interaction with the industry people:

"We are HVAC experts. CFD needs a separate expert team with different skill sets to use the software."

"Floor plans are available. But CFD needs a 3D Building Information Model to start with."

"Turnaround time for simulation results is high. It limits us to explore the entire design space. We need something swift to try 'What if' scenarios."

"Spreadsheets and rules of thumb for heat load calculations and sizing needs some change. We need something more accurate to ensure occupant comfort, air quality, and efficient air distribution."

"CFD is a costly affair for small/medium scale companies like us. It demands HPC setup, software installation, maintenance, separate licensing for single and parallel solvers, training..."

"Our workload varies throughout the year. We cannot afford to have an internal team and software-HPC setup. Outsourcing means providing design concepts to an external simulation expert and then waiting for the simulation results, to reiterate and improve the design."

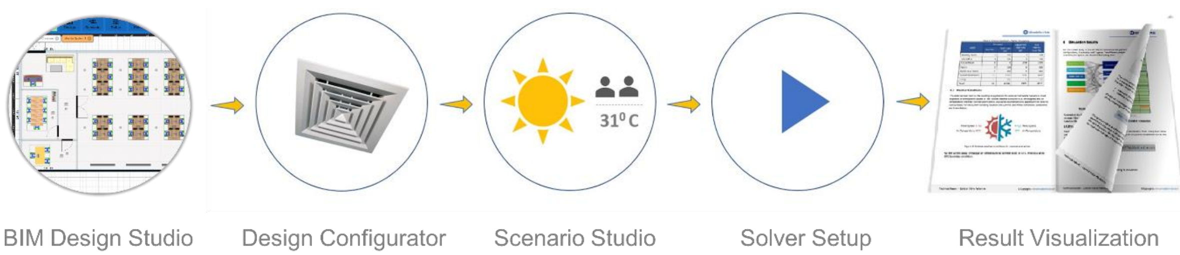
It clearly shows a need for democratization to take this powerful technology to every HVAC designer's hands. There is a need for an upfront CFD tool in the HVAC domain, which is accurate, fast, and affordable for the designer to converge to an optimum design in the shortest possible time. After processing all these inputs, the challenges listed out, and the following solutions formulated:

Industry challenges and possible solutions

No.	Challenges	Solution
1	Need for CFD expertise	An app that with automation and intelligence solve CFD challenges such as cad clean up, mesh cell size, boundary condition, turbulence model, solver setup.

2	Accurate solution	CFD settings that are well-validated with experimental/test data
3	3D Building design not available	BIM designer to sketch the 2D floor plan and convert into a 3D model
4	Software installation and annual maintenance, updates	Web app - Upload, case setup, submit solve and view results on web browse
5	Need for in-house HPC setup	CFD simulations on the cloud
6	Long turnaround times limits complete design space exploration	Scalable HPC cluster setup on a cloud with job schedulers to choose optimum compute nodes for quick results
7	License limitations put the simulation in que	Expandable cloud computing to run all the simulations parallelly on dedicated machines
8	Varying workload and project requirements	Subscription-based models to choose as per the demand

With these requirements in consideration, the simulationHub team has conceptualized the **Autonomous HVAC CFD** application as a web-based CFD app for HVAC designers and architects that runs CFD simulations on the cloud autonomously. The following workflow is formulated:



Autonomous HVAC CFD (AHC) app workflow

BIM Design Studio

The building design studio is where the user would create the building design spaces as per the floor plan and place the occupant seating positions.

- Specify site location and set building orientation
- Set material properties for – walls, glass windows, roof/ceiling, floor
- Canvas to sketch floor plan in 2D and option to preview model in 3D
- Sketching tools to create spaces - construct walls, place windows and doors on walls

- Select and place seating layouts with manikins, Furniture, lights, office appliances, etc... from a catalog of ready to use BIM components
- View details of space internal heat load

This stage also includes the creation of multiple air-side systems with different supply-return or A/C unit positions to try different air distribution system design - overhead mixing or underfloor air distribution. Airflow for cooling and heating design conditions for each space would be required as input from heat load and system sizing calculations.

- Select and place supply diffusers, return grills, A/C units from a catalog of ready to use BIM components
- Specify the summer and winter design airflow (cfm) for each supply or A/C units
- View details of ACH, cfm/person for each space

Design Configurator

In this stage, the user would use the air-side systems created in the BIM design studio to create multiple design configurations.

- Create multiple design configurations – CAV or VAV or user-defined supply conditions
- Create thermal zones and assign spaces to zones
- Specify thermostat settings and location
- Specify temperature and relative humidity of supply air

Scenario Studio

Scenario studio is the place where multiple simulation scenarios can be created. This could help to check the performance of the HVAC system in off-design conditions. The parameters to control are occupant load and external weather conditions.

- Set occupant density in each space – Full / Half / Partial load
- Set HVAC mode – cooling or heating
- Select ASHRAE design day or custom simulation day and time

This information would be required to set external weather conditions and to track sun position w.r.t the project site location and building orientation.

Solver Setup

In this stage, the user would select and add cases for simulation.

- View all the design configurations, scenarios, and spaces created in the previous stages
- Select a combination of design configuration, scenario, and space and add for simulation
- Display cost or simulationHub credits required for the selected simulations

Result Visualization

Once the simulations are completed, the user would get an email notification, and the results would be available to view and analyze the web browser.

- The select case for result visualization
- CFD post-processing tools – flowline animations, cut sections, surface plots, comfort cloud (iso-volumes)
- Comfort evaluation parameters – PMV, PPD, EDT, DR,… derived from CFD output data, i.e., velocity, RH, and temperature
- Auto-generated CFD report

Software Development Methodology

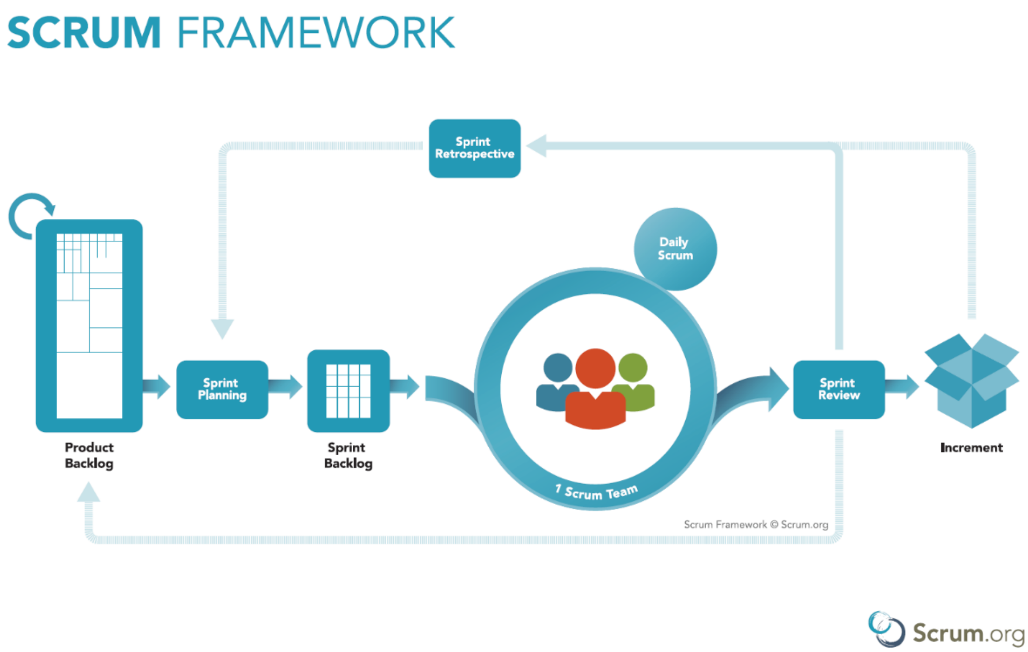
In this complex product development world, you need to be agile in delivering values to end-users. As per the [agile manifesto](), one should value

- Individuals and interactions over processes and tools
- Working software over comprehensive documentation
- Customer collaboration over contract negotiation
- Responding to change over following a plan

We are in the complex product development where more unknown and more unpredictable, if we apply command and control management style, it will not help in generating value, so we need to promote interaction and communication and servant leadership to create ideas and empower the team by creating a safe bounded environment for action.

We are using the SCRUM process framework to develop our product. We have one scrum team of 8 people, self-organizing and cross-functional, who delivers a product iteratively and incrementally. As scrum based on empiricism, we make sure everything is transparent to the team and stakeholders to inspect and adapt as required. We have one-week sprint to produce a done increment every week.

At simulationHub, we focus more on scrum values as Courage, Focus, Commitment, Respect, and Openness. They are our lighthouse and help us in decision making and to create a great and happy working environment in hyper-competitive environment.



Building Blocks

Standing on the shoulders of giants is the right way to start developing a web application. There is no point in reinventing wheels. To make a successful app, we need to identify the right components, the building blocks that will form a base for a great product. We try to explain why we choose a particular type of technology platform to learn from our selection.

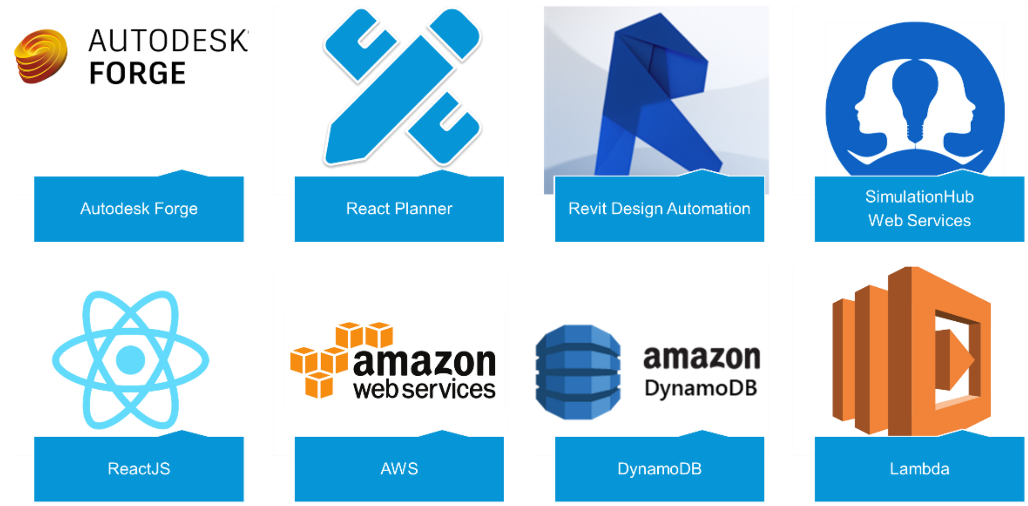
Technology Orchestration

While you are developing a web application, selecting the right technology stack is vital for your product success. Your application's skeleton contains frameworks, programming languages, tools, and different programming approaches.

In this process, one must answer the following questions. The answer to these questions help you shortlist the right option :

- What the best technology for the give functional objective?
- Does it satisfy our cost matrix?
- Is the technology secure, scalable, reliable?
- Are they provide active support?
- Does the company have resources and expertise in specific technologies?
- Will it help to accelerate the speed of development or vice versa?

We use this questionary to shortlist our technology stack. These are some of the industry's best components, and we highly recommend them for CAD, CAE, and CFD web applications development.



Autodesk Forge

One of the critical building blocks of our applications is the Autodesk Forge Platform. Forge is a cloud development platform with a robust and scalable set of APIs to build cloud applications with ease. When the simulationHub team started developing cloud applications in 2014, we were the first to use Forge in cloud-based simulation web application. Following are our reasons to go with the Forge platform:

- Easy to use and master
- Speed of development
- Robust and Scalable API
- Highly Secured
- Affordable
- Complete ecosystem
- Excellent User Experience

React Planner

For sketching the design intent of a user, we needed a highly efficient sketcher library. Our choices to develop something from scratch or to look for the ready component.

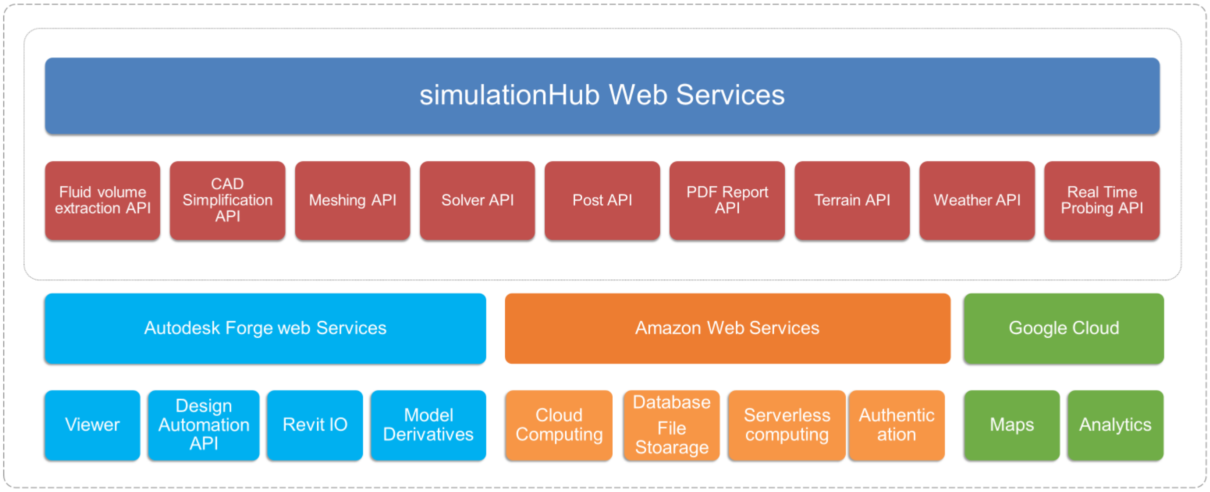
React Planner, a ReactJS based opensource application framework designed to draw 2D building layouts. The app uses a highly customized react planner component for BIM designer and provide many features for HVAC systems

Drag & drop from a catalog of customizable and ready-to-use objects; you can start from 2D wireframes and land on 3D models. As a developer, you can provide your users with new items by adding them to the catalog.

It also provides access to the 3D model of the design created using the Three.js package. It provides better visualization for the designers to place the floor plan components for a realistic virtual interior.

SWS - simulationHub Web Services

The heart of this application is a CFD simulation. Fortunately, we did not need to look anywhere else. We have been building simulationHub Web Services (SWS) for the past five years. SWS is the world's first CFD microservices. They helped to take care of a big chunk of the workload in building an Autonomous HVAC CFD application.



simulationHub web services

simulationHub web services facilitate developed to perform CFD operation by invoking simple REST API. They are fully managed with scalable cloud infrastructure. Developer concentrates on CFD process, and SWS take care of all the automation challenges to run the jobs. It's an intelligent platform that provides an autonomous solution for CAD clean up, meshing and solver parameters setup, and smart post-processing. SWS offers extensive API for other relevant operation for geometry processing, weather information, terrain information, etc

Front-end framework - Choice of plenty

Front-end Development is a medium to represent data in a graphical representation using tools such as HTML, CSS, JavaScript. In today's scenario, web-development has become more comfortable with the advancement of multiple frameworks and libraries.

The most used front-end tools include AngularJS, ReactJS, MeteorJS, VueJS. These libraries / Frameworks provide ease of development for the Graphical User Interface of the application.

We decided to develop our applications using the ReactJS Javascript library. ReactJS uses VirtualDOM, which updates only those components which are changed, making the rendering far better. Unlike ReactJS, MeteorJS, and AngularJS refreshes and reloads the complete DOM, increasing the loading time.

One of the critical features of ReactJS is the reusability of the components created, thereby reducing the redundancy in the codebase. This reusability does not affect the DOM when one element is updated. It also uses the JSX templating language, which helps develop the component using HTML and JS. The HTML tags are converted into React Elements, thereby giving a refined look into designing the User Interface.

Both ReactJS and AngularJS support TypeScript language syntax, making the source code easier to read and understand, avoiding the incorrect variable type.

Cloud Platform Conundrum

While building a web application, we need to choose the right cloud service provider. Today top three cloud service providers are AWS, Azure, Google Cloud Platform, while Oracle and IBM are also competing for the market share.

Cloud solution architects help the teams in identifying the mico services needed for building an app. We listed which cloud services we needed the most and availability with all cloud providers for our application.

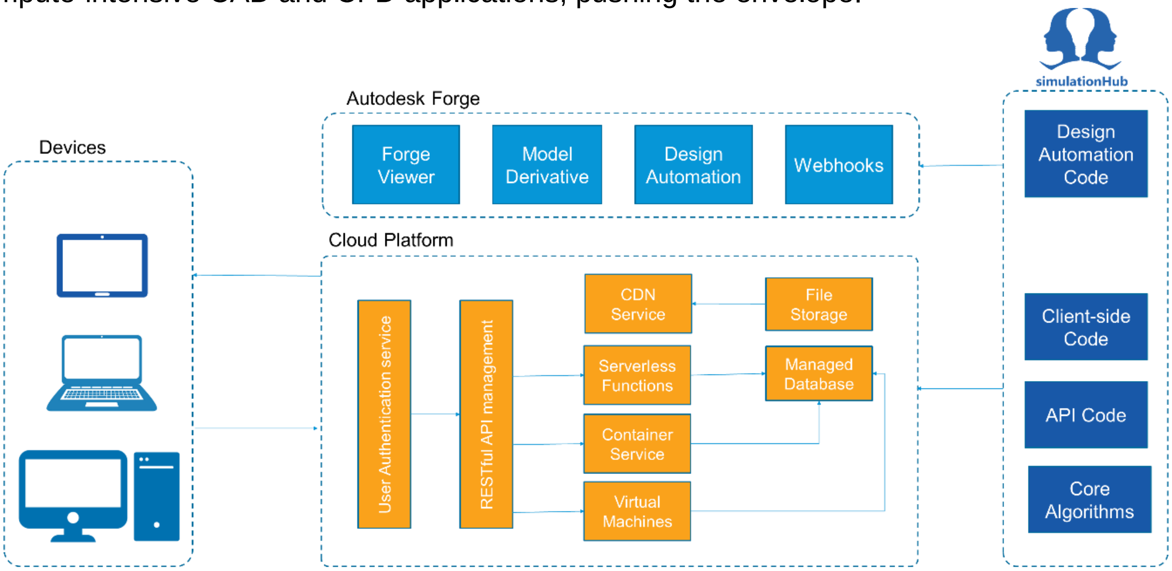
Based on the number of services available, the cost of services, and the uptime, we decided to host our application on the AWS cloud.

To be or not to be serverless

We realized that server-hosted cloud applications' most significant cost factor is running the server from our web application development experience. We decided to take a radically new approach to go with serverless computing.

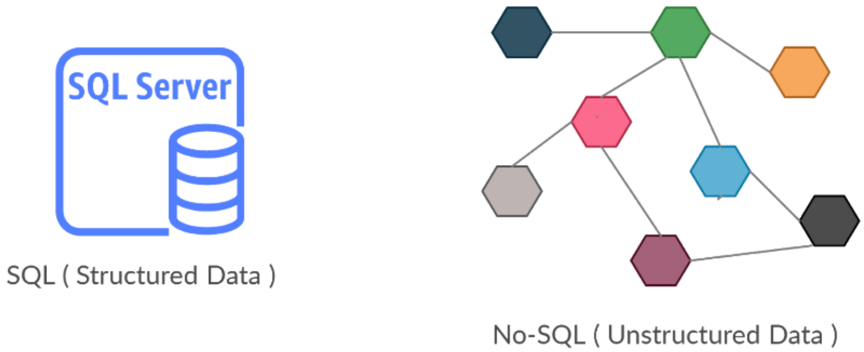
Serverless computing needs a new strategy to write the code. It also has limited memory, hard disk, and time of execution.

The most significant advantage of serverless computing, a lambda function in AWS, is it very affordable. They are also highly scalable. We can serve millions of customers easily using serverless computing. They are generally known for light operation only, but we used them in compute-intensive CAD and CFD applications, pushing the envelope.



Database

Any application heart is its database. Developers from the desktop background are more familiar with the SQL database. However, they become less attractive to cloud applications.



Types of Database

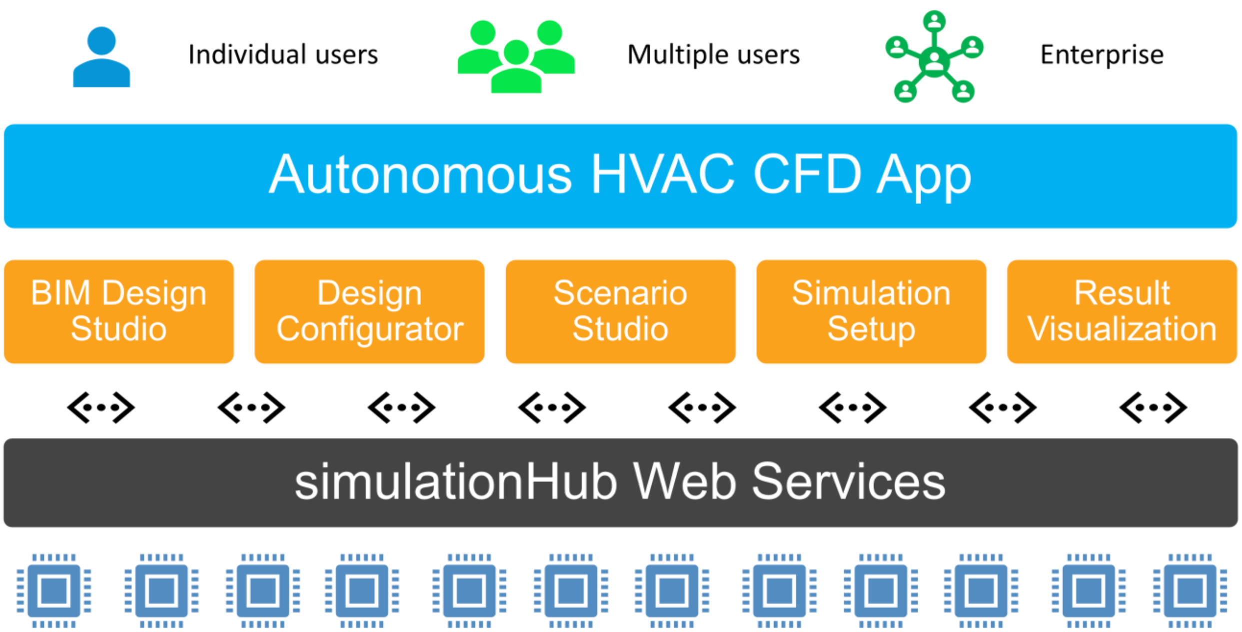
We decided to use DynamoDB as our key database solution. Amazon DynamoDB is a No-SQL database that has very minimal response time. It helped to releases us from the responsibilities of hosting, scaling a distributed database. It stores data in the form of key-value pairs. It also offers replication of data across various AWS regions, which results in fast access of data globally. It is serverless, releasing the customers from managing servers, installing, or maintaining or operating software. It is the best choice when you need to follow Brewer's CAP theorem, i.e., consistency, availability, and Partition tolerance. By default, all the data stored in DynamoDB encrypted format.

Autonomous HVAC CFD application

Autonomous HVAC CFD (AHC) application is an upfront CFD tool to perform a large number of HVAC CFD simulations on the cloud, autonomously. The app provides a platform for HVAC engineers, manufacturers, architects to explore the entire design space and evaluate the occupant thermal comforts for multiple HVAC design configurations and several thermal load scenarios.

Architecture

Web-app follows the various type of client-server architecture model. Autonomous HVAC CFD is built with the following architecture model. It's a stateless app that is authenticated by multiple login options. Most of the applications code is in the running on servers that means excellent security and speed. It is a highly scalable app that can host thousands of users at a time and millions of interactions.

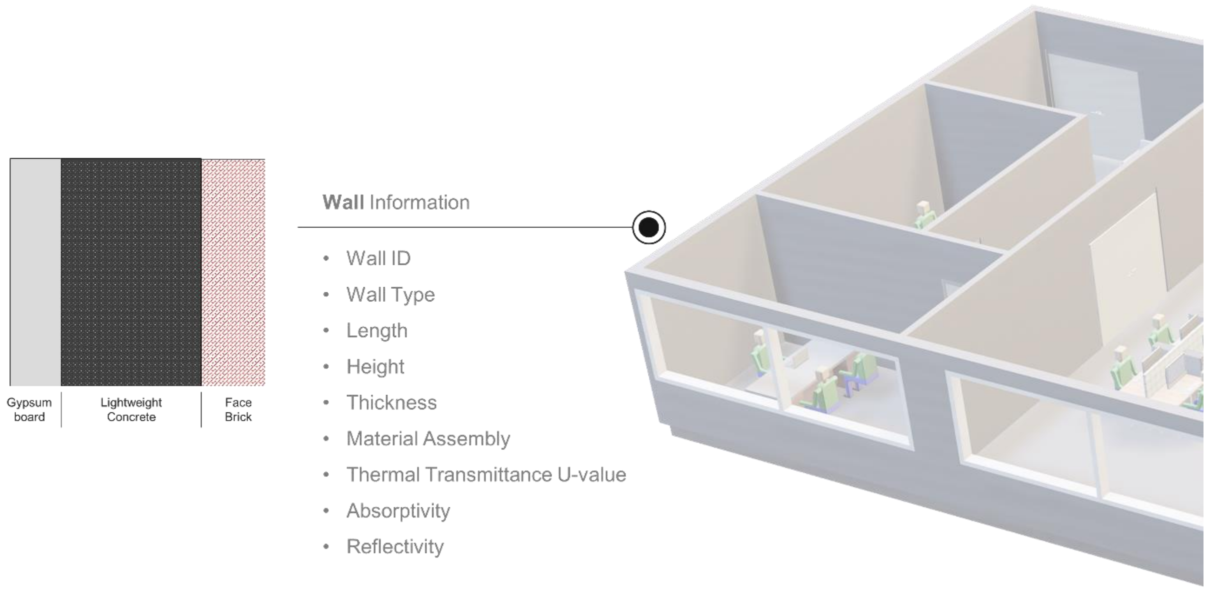


Five essential components of the app are:

- BIM Design Studio
- Design Configurator
- Scenario Studio
- Simulation Setup
- Result Visualization

Data Journey

Autonomous HVAC CFD has an innovative data model build for a specific problem. The application starts with a user drawing a space layout in BIM Design Studio based on a 2D drawing from their customers. Several other information was collected from the user, such as building material properties, thermal properties, furniture layout, office equipment, flow equipment, and others—all of this data stored in vector form. Rich handling of data provides tremendous value to the user as he can make any number of changes at any place. Thus, helping him in report generation and tracking history.

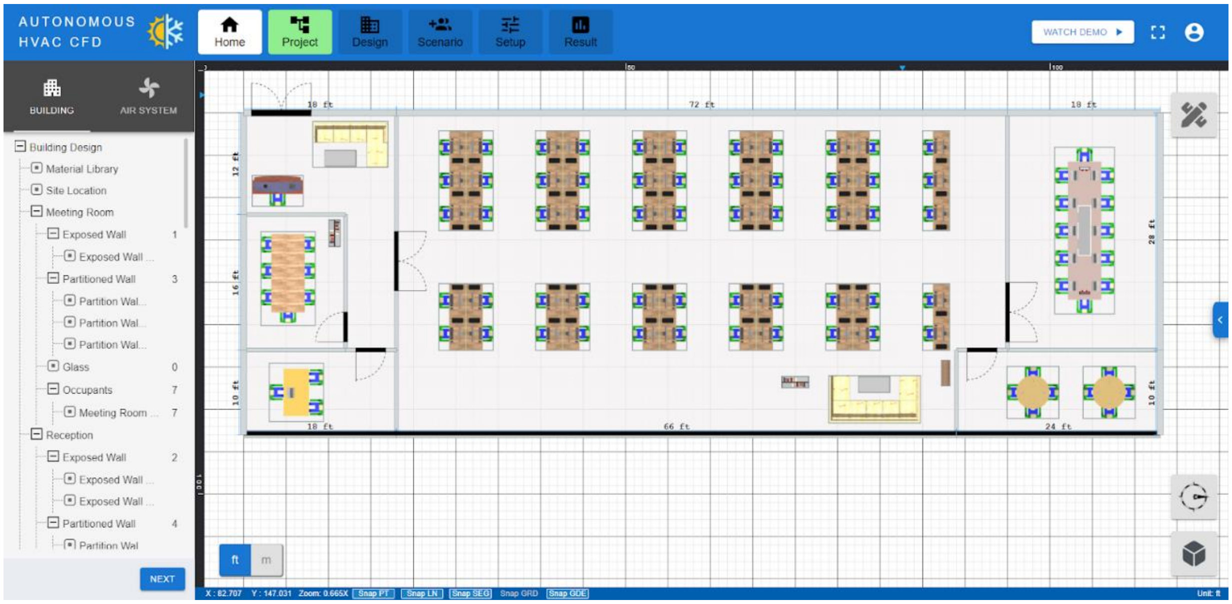


All the parametric data captured by BIM Design Studio helps algorithms in autonomous decision making and self-learning. As user progress in application creates several design configurations and scenarios for large spaces, just one project can generate a terabyte of data from hundreds of simulation execution. Application has a novel way to serve any slice of a terabyte of data in less than 60 seconds, a unique feature.

UI/UX Design

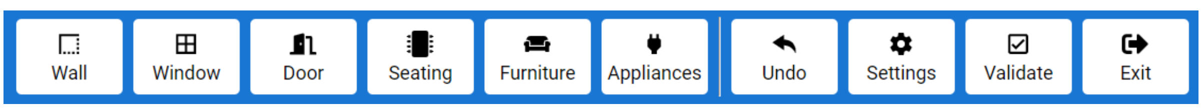
User Interface and User Experience design enhances user satisfaction with a product by improving the usability, accessibility, and pleasure of the interaction with the product. Good user experience design is always part of the product development process.

Following are a few highlights of the AHC app UI/UX design:



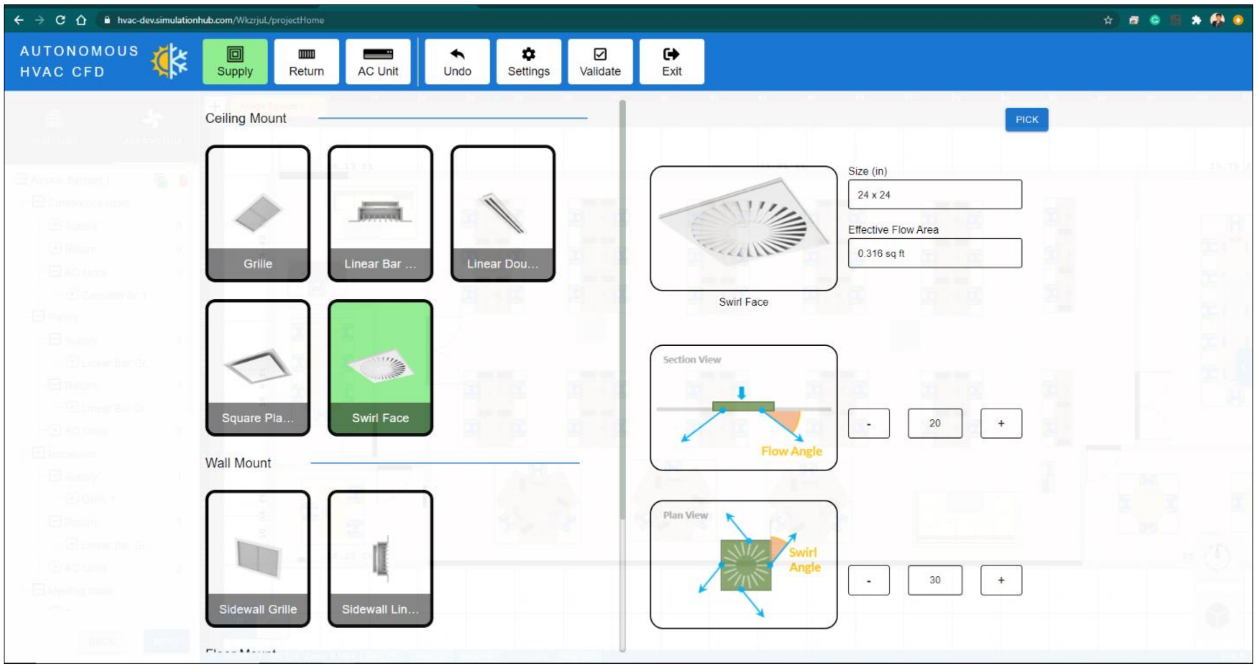
User Interface (UI) of the AHC app – BIM design studio

One of the app's main objectives is to provide a platform to sketch the floor plan in 2D and convert it into a 3D BIM model ready for simulation. The sketch mode in **BIM Design Studio** has options to construct walls, windows, and doors. Users can also add Furniture with occupants' seating layouts and office appliances such as projectors, copiers, and lights. Finally, the user can validate the overlaps and proximity checks model before moving to the next stage.



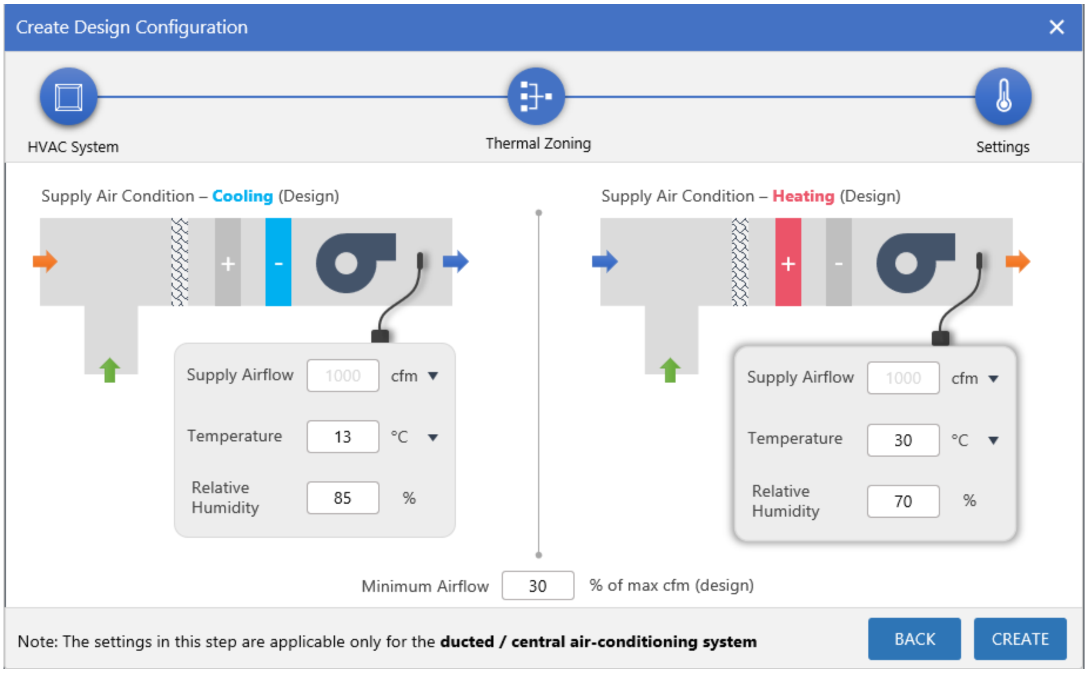
Sketch mode tools for creating building space

The sketch mode in the air-side system has options to add Supply-Return outlets or A/C units. A library of diffusers is available for the users to select from the list. Additionally, the user can also specify the size and flow angle details.



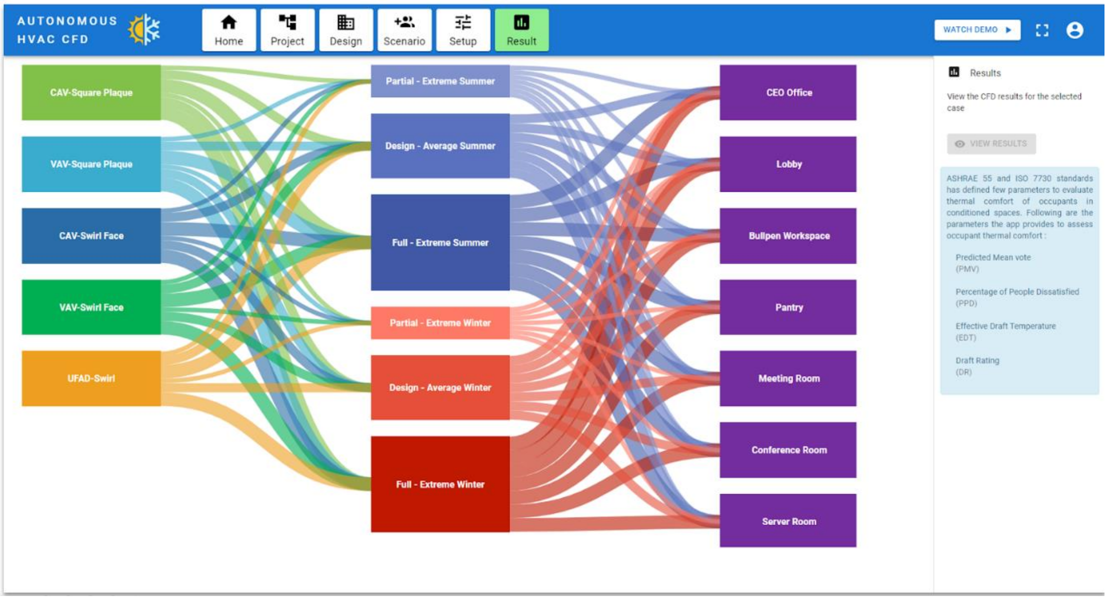
Sketch mode tools to create air-side system

Skeuomorphism is a user interface design style used to describe interface objects that mimic their real-world counterparts in how they appear and how the user can interact with them. It allows the user to feel a connection with the app as the objects seem familiar. The app includes this style of UI objects and references throughout the workflow to assist the user in problem setup.



Supply air condition input at the outlet of Air Handling Units (AHU)

Sankey Chart: The app provides options to create multiple design configurations and scenarios for the building spaces. But the app uses an exciting way to display these combinations to select cases for simulation using the Sankey chart.



Sankey chart to select cases for CFD simulation

God is in Implementation

Finally, it all comes down to the effective implementation of our ideas, strategy, and planning. After selecting the correct technology set, the app development's next phase is implementing features and functionality.

BIM Design Studio with React Planner

The BIM Design Studio builds with react Planner, which is ReactJS based application designed to make 2D building designs. The app uses a highly customized react planner component for BIM designer and provide many features for HVAC systems

It also provides access to the 3D model of the design created using the Three.js package. It provides better visualization for the designers to place the floor plan components for a realistic virtual interior.

React Planner Architecture

The React Planner project consists of 5 main components for creating a proper building design. These components are the classes that serve their purpose in designing a building model. These are:

- **Areas Class:** It contains all the data of the Spaces Created in the project
- **Vertices Class:** This class holds individual vertex data used for the creation of the above spaces
- **Lines Class:** This class deals with all the walls created in the project, and depending on the wall located in the space, it distinguishes the wall type as Exposed or Partition
- **Items Class:** This class handles all the components placed in the floor plan, i.e., items of Furniture, Seating arrangements, Air Terminal Units.
- **Holes Class:** This class handles all the Wall Mount components placed in the floor plan. This includes the Window and the Ait Terminal Units.

The following customization has been added to the React Planner application to satisfy the software requirements.

Catalog Customization

The application has a modified catalog by adding custom Seating Arrangements, items of Furniture, which have been designed in-house.
The Application catalog includes the following items:

- Furniture
    - 3-Seat Sofa
    - L-Shape Sofa
    - U-Shape Sofa
    - Bookcase
    - Trolley Bookshelf

- Seating Arrangement
    - Reception Desk
    - Private Cabin Seating
    - Conference Room Seating
    - Private Meeting Room Seating
    - Rectangle Seating Arrangement
    - Cross Seating Arrangement
- Air-Terminal Units
    - Square Plaque
    - Swirl Face
    - Underfloor Twist Pattern
    - Linear Bar Grille
    - Linear Double Slot
    - Grille
    - Cassette AC
    - Wall Mount Split AC

Geometry Validation

While creating a Floor Plan, the designer ensures that the occupant gets the maximum room space available to feel comfortable. The validations that the application includes ensure that the user's Floor Plan meets the proper workflow of the application.
Key validations include:

- Distance between the walls of the space and the Furniture / Air Terminal Units should be above the minimum distance
- Distances between each Furniture / Air Terminal Units placed should be above minimum distance
- The components placed outside the canvas are not created.

Automatic Wall Type Identification

One of the necessary customization added is the differentiation of Wall Types.
We have a total of 2 Wall Types:

- Exposed Wall
- Partition Wall

Depending on the floor plan's wall, the walls type if identified, and then appropriate properties are assigned.

Support for multiple file types in 3D

The original 3D rendering of the catalog items was supported in an OBJ file format only, a bulky file format for loading 3D models. We have modified this 3D rendering support of an OBJ file format to a GLTF file format, thereby decreasing the loading time of the models in ThreeJS and reducing the application's storage volume.

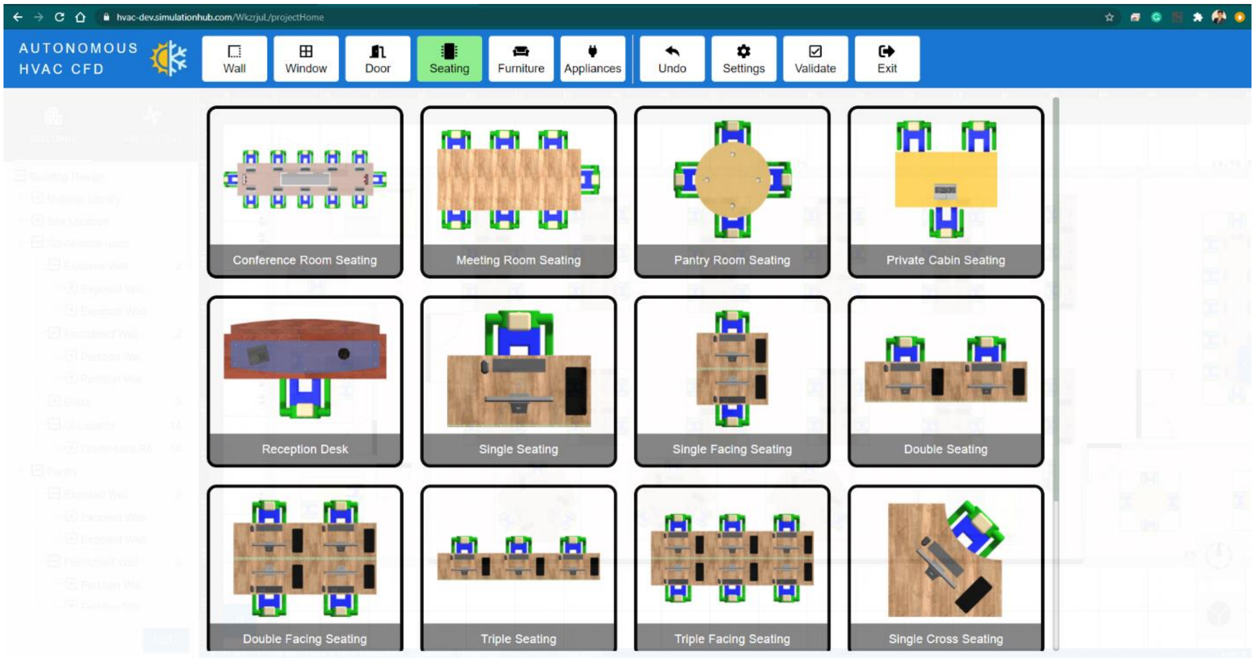
BIM Components

BIM object is the digital product information which involves the creation of a building product in a 3D format with associated technical data, converted into digital formats compatible with design software.

Ready to use BIM components developed with advanced features like nested family and parametric designs. The air-side system consisting of diffusers and air conditioners, developed following the HVAC standards. The simulationHub design team has made the components in units and assembly structures to achieve freedom and flexibility in the designing process. Industry design standard (ANSI/BIFMA) referred to them as design BIM objects.

Seating Layout Catalog

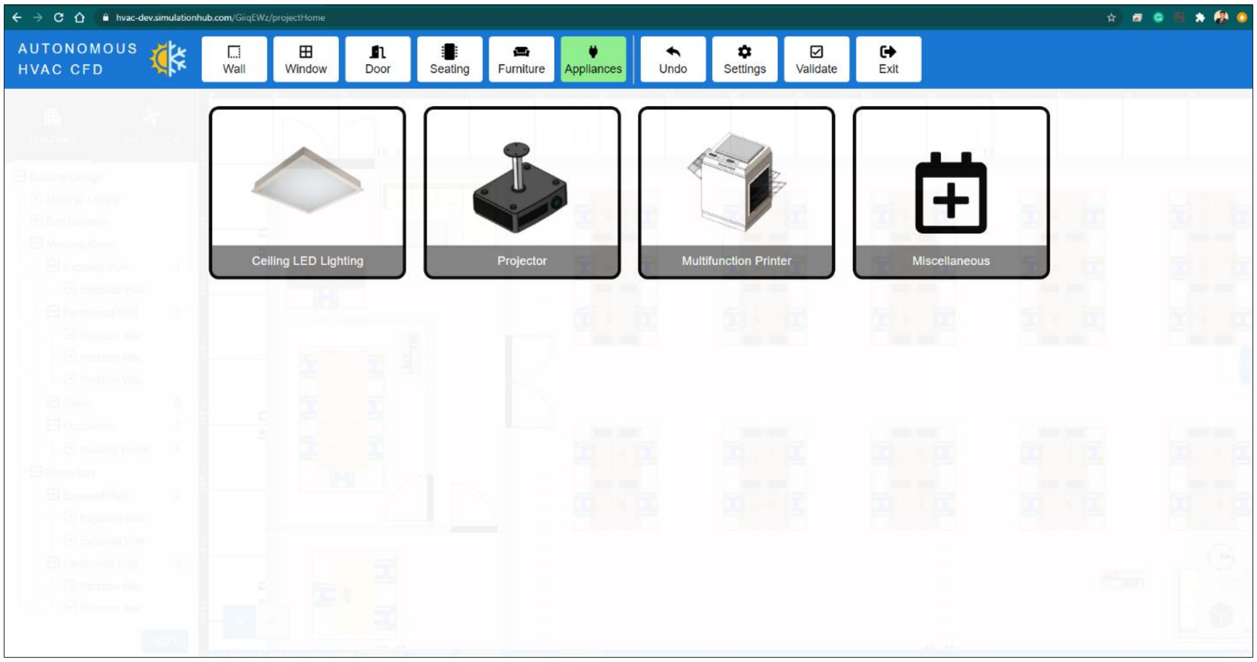
The seating catalog provides 15 ready-to-use BIM components of layout options with different seating capacity for typical office spaces – workspace, meeting/conference room, private cabin, reception, pantry. The design layouts include heat loads like thermal manikins, computers, laptops as part of the component. All thermal manikin has information like heat load and clothing insulation associated with them. The catalog enables users to quickly select from the list and arrange the seating on the created space floor, as per their requirement.



Catalog – Seating layouts with manikin and computer/laptop

Office Appliances Catalog

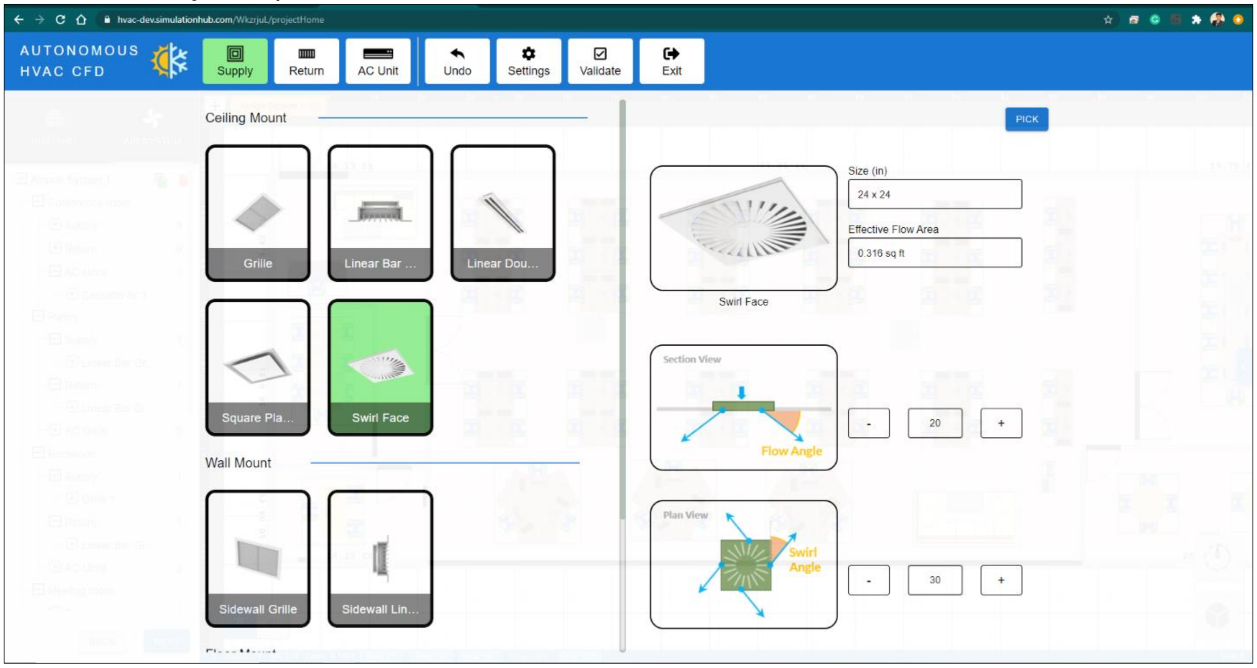
A separate catalog for other heat-generating equipment/appliances – ceiling LED lights, projectors, multifunction printer/copier. Users can select the required appliance and place them in the appropriate position in space. All these appliances have a fixed size, and heat gain value is associated with them. 'Miscellaneous' option can be used for any custom size and heat load value.



Catalog – Heat generating appliances in office setup

Supply Diffuser Catalog

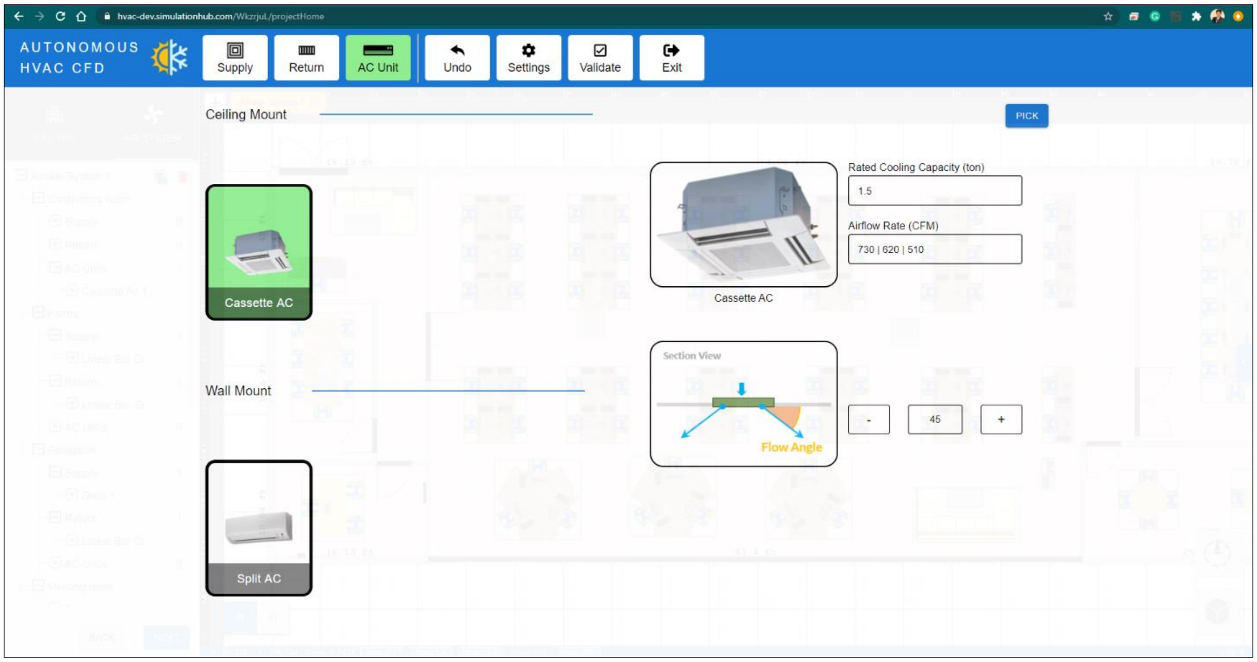
This catalog has a wide range of supply diffusers to create different centralized HVAC system design configurations. The diffusers are categorized based on their mount – ceiling | wall | underfloor. All supply has multiple size options to select from, and the application displays the effective flow area. Users can specify the flow/swirl angle and design airflow (CFM) to get the realistic velocity flow profile.



Catalog – Supply diffusers and grills for centralized/ducted AC system

Air Conditioning Unit

This catalog has individual Room A/C units like Cassette and high wall-mount units to create ductless HVAC design in some building spaces. Users can specify airflow (CFM) and swing angle for the selected components.



Catalog – Individual room AC units

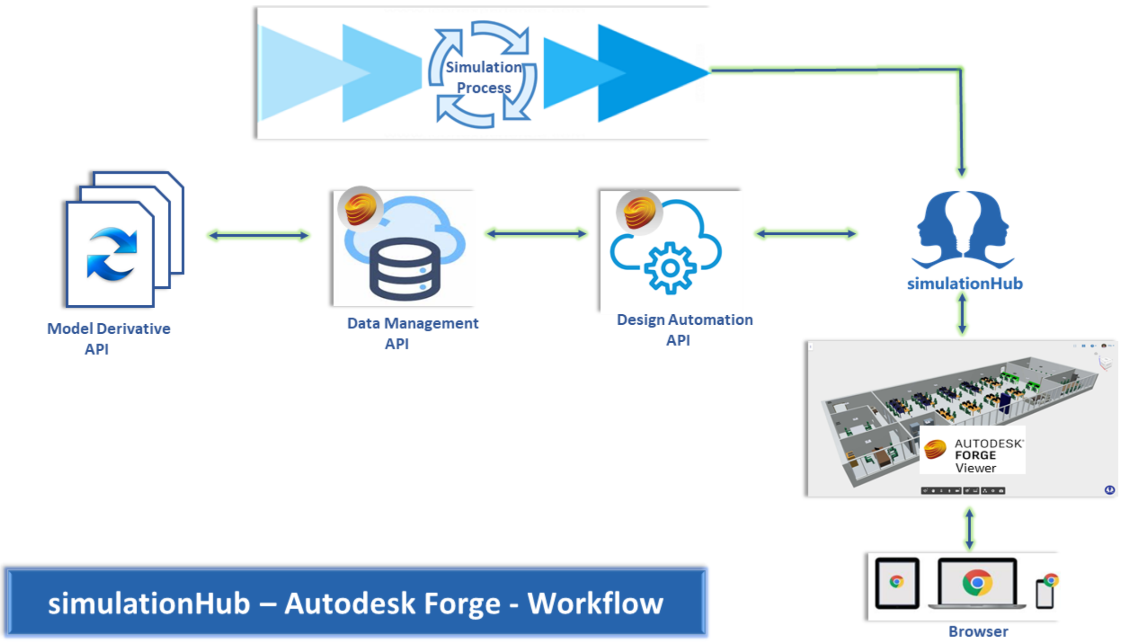
Currently, we support a total of 16 supply, return, and A/C units. In the future, HVAC manufacturers would add their products to the app library to see them listed in the catalog.

Autodesk Forge Integration

In simulationHub, we are using model derivative API, which helps us understand most CAD file formats and generate Autodesk Forge viewable. Our favorite component is Design Automation services. We have created many custom algorithms which use Autodesk Inventor and Autodesk Revit

Model Derivative API

In simulationHub software, users need to upload CAD files. Understanding those many CAD file formats and generating a viewable component, we use model derivative API. It helps to understand the file structure, enables users to represent and share their designs in different formats, and extract valuable metadata. After translating this, the user can view this in the Autodesk Forge Viewer.



Forge Viewer

Autodesk Forge Viewer, which is a WebGL-based, JavaScript library for 3D and 2D model rendering. These 3D and 2D data may come from various applications such as AutoCAD, Autodesk Inventor, Revit, or any other CAD application. The simulationHub applications need to be highly responsive and require reloading new geometries very quickly to provide a good user experience, and the Viewer helped in delivering a seamless experience.

Also, we used Forge viewer to visualize simulation results like flowline animations, cut sections of contours, surface plots on the Viewer. Very rich visualization data can be embedded in the Viewer and showcase to the user in less than a min.

Design Automation API

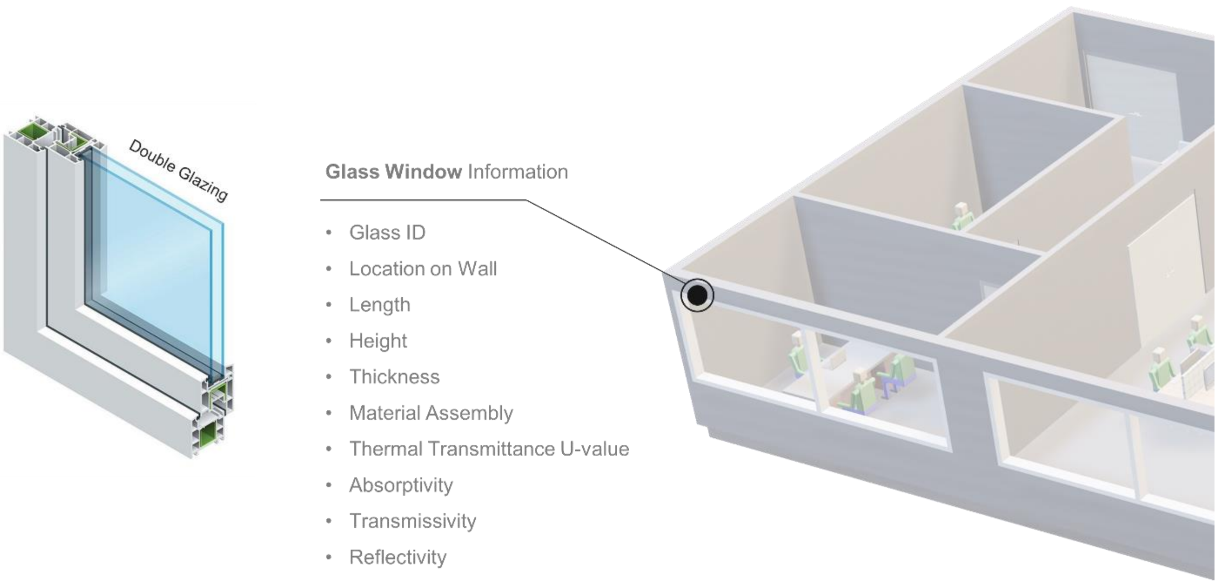
Design automation runs your custom automation scripts on your design files in the cloud. The Design Automation API provides the ability to use the core API's of CAD engines in the cloud, leveraging the Forge Platform scale to automate a task. Design Automation API helped simulationHub by offloading that processing to the Forge Platform, which can process those jobs at a much grander scale and efficiency. We are using a Revit and Inventor engine in many of our services.

Revit Design Automation

Revit Design Automation API is a Revit engine running in the forge cloud, and we can use all the core Revit DB API to create and process BIM files. We can use such APIs to create custom workflows with RFA files and extract data from Revit files.

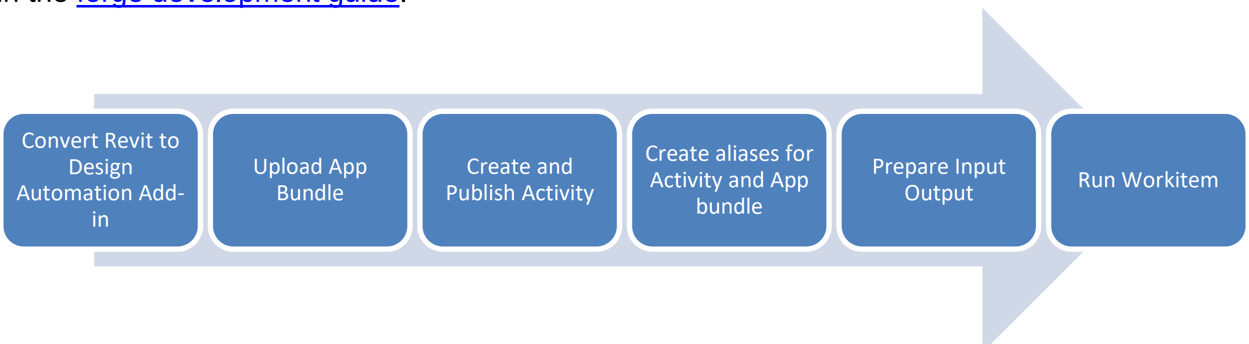
In our application, we are using Revit Design Automation for two process

- Creating a BIM model using our BIM Design Studio files
- Extract fluid volume for different building spaces
- Extract metadata from different BIM component used in our HVAC systems



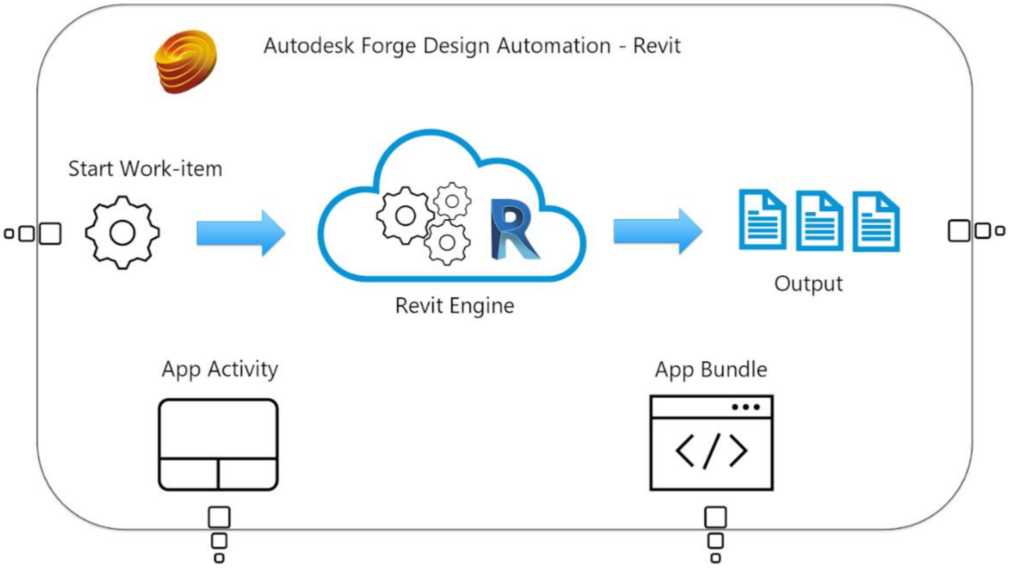
Design Automation Add-in

Converting the Revit plugin into the Design Automation project is a simple process documented in the [forge development guide](#).



For locally debugging and troubleshooting purposes, we can use Design Automation Handler Projects published on [GitHub](#).

For ease of deployment of both app bundle and new activity, Autodesk published an extension on the Visual Studio Code, which helps to issue more recent versions in a couple of minutes. Before this tool, it was a quiet time-consuming set of API calls needed, which now works on a button click. You can find a detailed [blog](#) on the exact usage of the extension.



Design Automation Components

While working with Revit Design Automation, you need to understand one windows working directory created for each work item, and all your input files are placed in the working directory. Your app bundle would have access to the respective working directory and its child directories.

App bundle

The App bundle is a directory structure that contains a package XML file (standard bundle package file) with binary DLL files of your app and their dependencies. If you wanted to load different RFA files in your application, you might include such files app bundle

You can create multiple aliases for your app bundle for different environments like production and testing, and development and can have different versions of scripts

App Activity

App Activity is generally the input and output structure for your app bundle with an engine. You can also create various aliases for production, testing, and development environments.

Work-item

When you are ready with your app activity, you can start executing the activity with corresponding input, output, and create a work item. You can monitor your work item's progress and check the success/failure of the work item. Detail logs are available when the work item execution is complete.

Revit Design Automation Code Snippets
Following code, snippets should help the developer understand how various BIM elements can be easily created using Revit API.

Creating Different Wall Types based on the thickness

```
private Autodesk.Revit.DB.WallType createWallType(Document document,
double wallThickness, String WallType)
{
    FilteredElementCollector collector = new FilteredElementCollector(document
    );
    var collection = collector.OfClass(typeof(Autodesk.Revit.DB.WallType)).ToE
lements();
    Autodesk.Revit.DB.WallType wallType = collection.First() as Autodesk.Revit
.DB.WallType;

    Autodesk.Revit.DB.WallType wall = wallType.Duplicate(WallType) as Autodesk
.Revit.DB.WallType;
    var wallCompoundStructure = wall.GetCompoundStructure();
    wallCompoundStructure.SetLayerWidth(0, wallThickness);
    wall.SetCompoundStructure(wallCompoundStructure);
    return wall;
}
```

Creating a wall

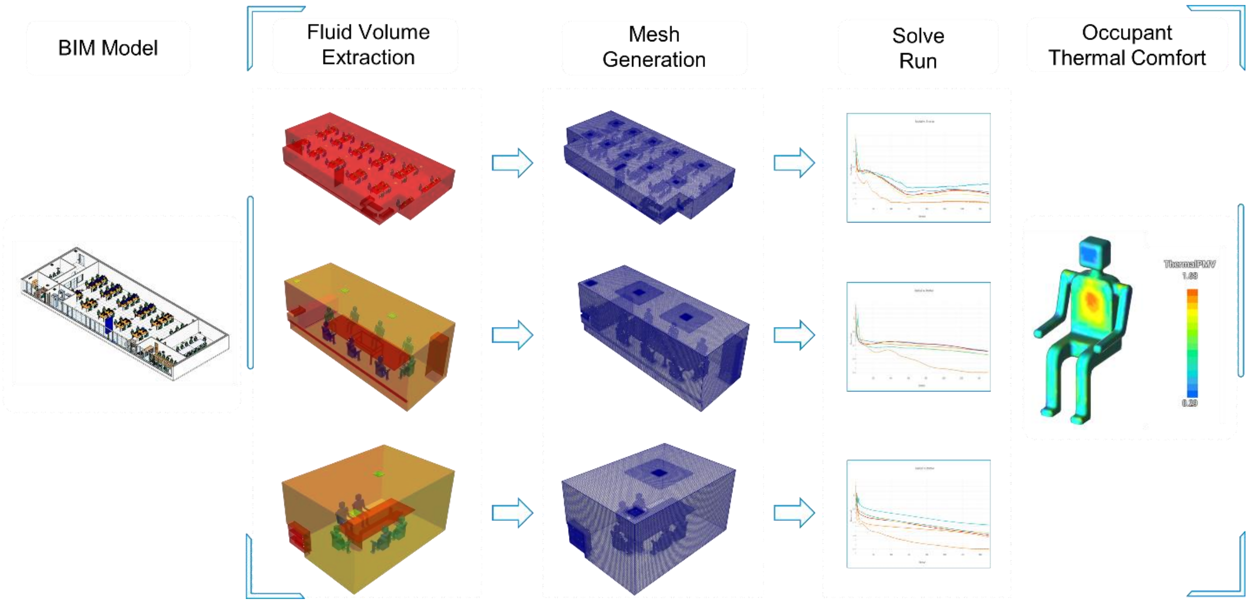
```
private void createWalls(Document document, ElementId level_id1,
ElementId level_id2, XYZ point1, XYZ point2,
Autodesk.Revit.DB.WallType wallType)
{
    double ceilingHeight =(document.GetElement(level_id2) as Level).Elevation;
    Curve curve = Line.CreateBound(point1, point2);
    Autodesk.Revit.DB.Wall wall = Autodesk.Revit.DB.Wall.Create(document,
curve, wallType.Id, level_id1, ceilingHeight, 0, false, false);
    Parameter parm = wall.LookupParameter("Top Constraint");
    parm.Set(level_id2);
}
```

Creating Room from a set of points

```
private void createRooms(Document document, ElementId level_id1, double ceilin
gHeight)
{
    //Get Non Construction Phase
    Phase phase = document.Phases.get_Item(1);
    PlanTopology planTopology = document.get_PlanTopology(document.GetElement(
level_id1) as Level);
    int roomID = 0;
    foreach (PlanCircuit planCircuit in planTopology.Circuits)
    {
        roomID++;
        if (null == circuit)
            continue;

        Autodesk.Revit.DB.Architecture.Room newScheduleRoom = document.Create.
NewRoom(phase);

        string newRoomNumber = roomID.ToString();
        newScheduleRoom.Name = "Office Room " + roomID.ToString();
        newScheduleRoom.Number = newRoomNumber;

        newScheduleRoom=document.Create.NewRoom(newScheduleRoom, planCircuit);
        newScheduleRoom.LimitOffset = ceilingHeight;
    }
}
```

Autonomous CFD simulation setup

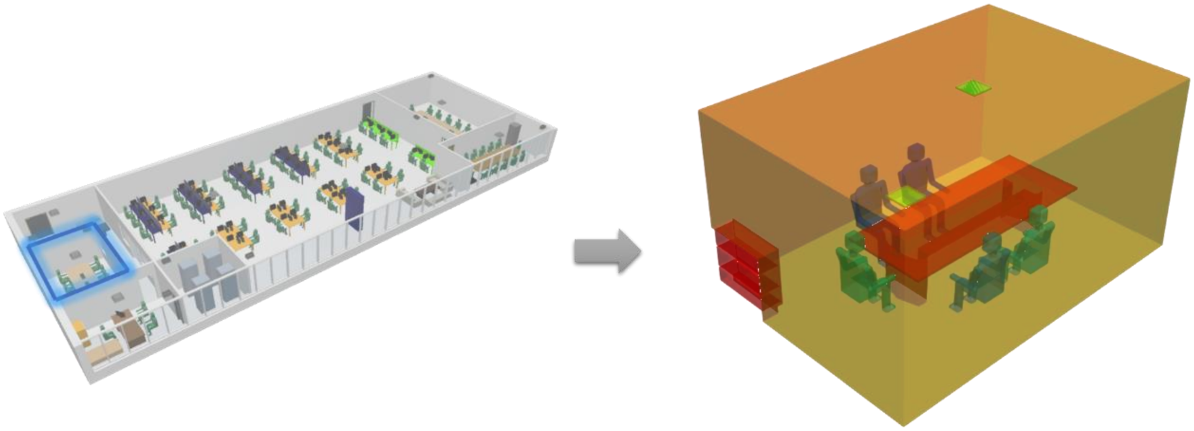
One of the most critical aspects of AHC app is its ability to configure and execute the complete CFD process autonomously. We have developed many proprietary algorithms that produce meaning simulation without human intervention. We have also developed machine learnings based on self-adapting methods to achieve full autonomy. Autonomy has helped us encapsulate the complete CFD process in microservices on the simulationHub Web Services platform. Each of the microservices takes a range of REST API parameters and executes the defined job on independent machines. Therefore all of our CFD microservices are highly scalable and resilient systems.



CFD Process – BIM model to Comfort plot

Following are the four critical microservices of the complete CFD process:

Fluid Volume Extraction Microservice



Autonomous Fluid Volume Extraction (FVE) from BIM model

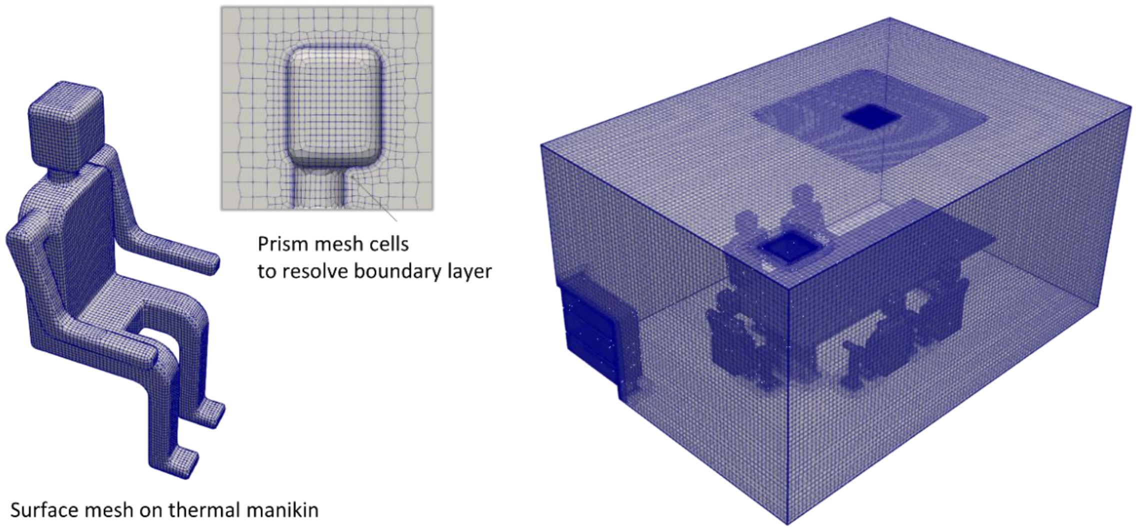
Fluid volume extraction means extracting wet surfaces from the building design model. These are the surfaces that come in direct contact with the conditioned air. CFD analysis requires a water-tight fluid volume for meshing. It includes identifying the wet surfaces and closing the small gaps/leaks in the building design model. The input model generally has detailed geometry features and might have some unwanted gaps that could cause quality-related severe issues in the meshing process.

Some gaps in the geometry are meant to be retained. For example, the effective flow area of supply diffusers needs to be treated as inlet surfaces. The AHC app uses simulationHub proprietary algorithm to extract the required fluid volume, autonomously.

HVAC Meshing Microservice

A CFD model requires the fluid volume to be divided into discrete elements (made up of geometric primitives like hexahedra and tetrahedral) or cells. The governing equations are then discretized and solved inside each of these cells. The collection of all these elements or cells is called a mesh. The distribution of these mesh elements defines the level of accuracy.

The app meshing algorithm assigns appropriate element sizes to ensure an adequate number of cells to resolve the geometry and flow field. A refined mesh has been used around the heat sources(thermal manikin) and diffusers to increase the mesh density in the interest areas to ensure the flow field has been accurately resolved. Additionally, layers of prism cells are generated on the manikin surfaces to capture the thermal & flow boundary layer physics.



Autonomous meshing of spaces with prirsm layers around heat load (manikin)

HVAC Solver Microservice

CFD solves the Navier Stokes equations governing fluid flow over a computational domain. The turbulent behavior of flow is solved by using the RANS (Reynolds Average Navier-Stokes) approach. k-ω turbulence model is used to model turbulent effects inside the space.

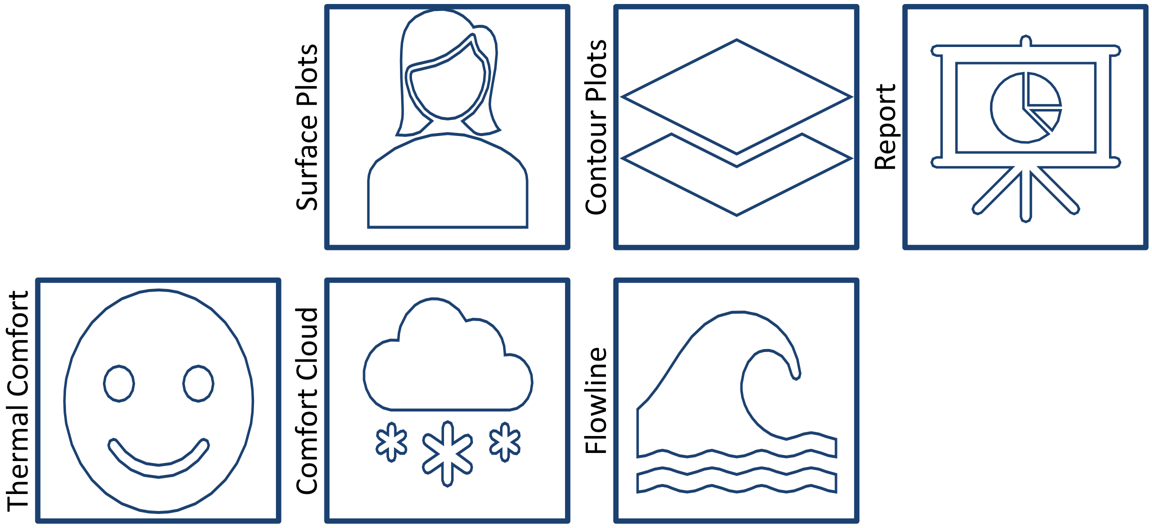
Solar load modeling plays a vital role in HVAC simulations. It is generally calculated by the raytracing of solar radiation and applying the high fluxes on exposed surfaces that demand radiation physics modeling in the simulation.

As the optimum Relative Humidity (RH) required in the space varies from 30-50%, which has an absorption coefficient of 0.17 to consider the medium as an optically thick and finite Difference Ordinate Model (DOM) is the suitable model for this physics. The RH distribution in the space varies a lot in the Room from the hot sun-exposed surface to the beneath supply diffuser. Hence assuming constant all over the domain is not correct. Therefore, it is captured by solving the active scalar transport equation for the moisture.

The app has a 1e-04 convergence criterion set to measure the solution's imbalance, ensuring the equations are solved with acceptable accuracy.

Post-Processing Microservice

One of the crucial aspects of the generated results is that they are easily accessible on a web browser and interactive. The CFD simulation data is processed, and essential information is extracted by doing Post Processing operations. The app provides more post-processing features to analyze and understand the flow behavior, which helps design an optimum air distribution system for the conditioned space.

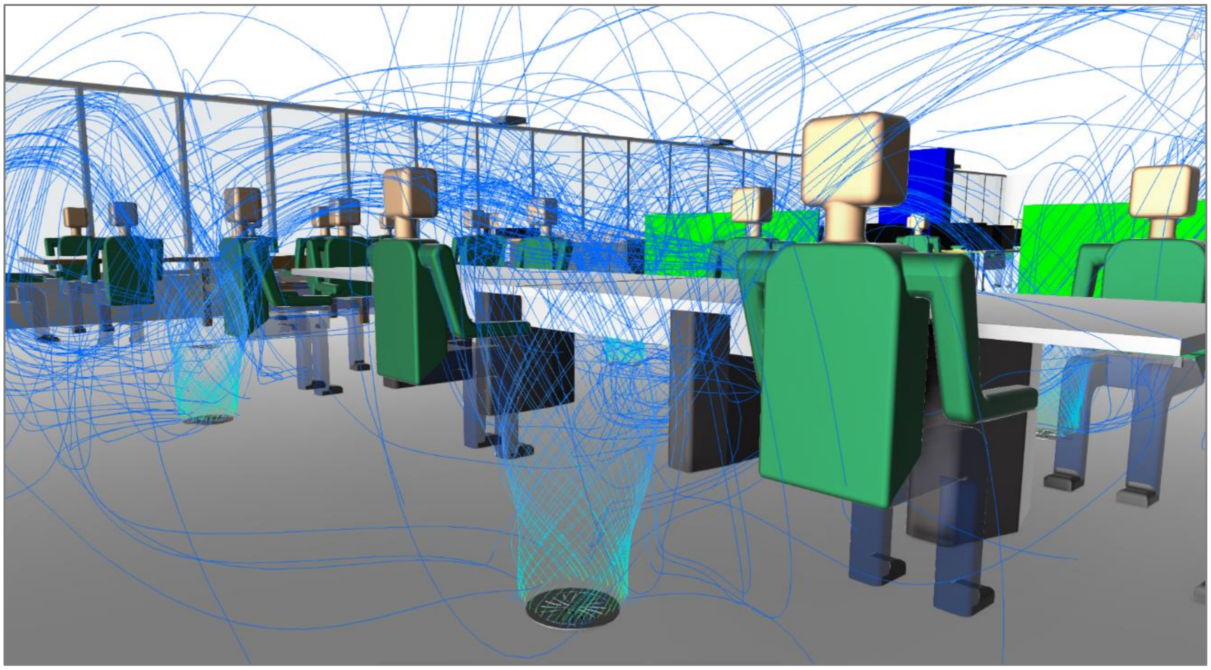


Post-processing tools in the AHC app

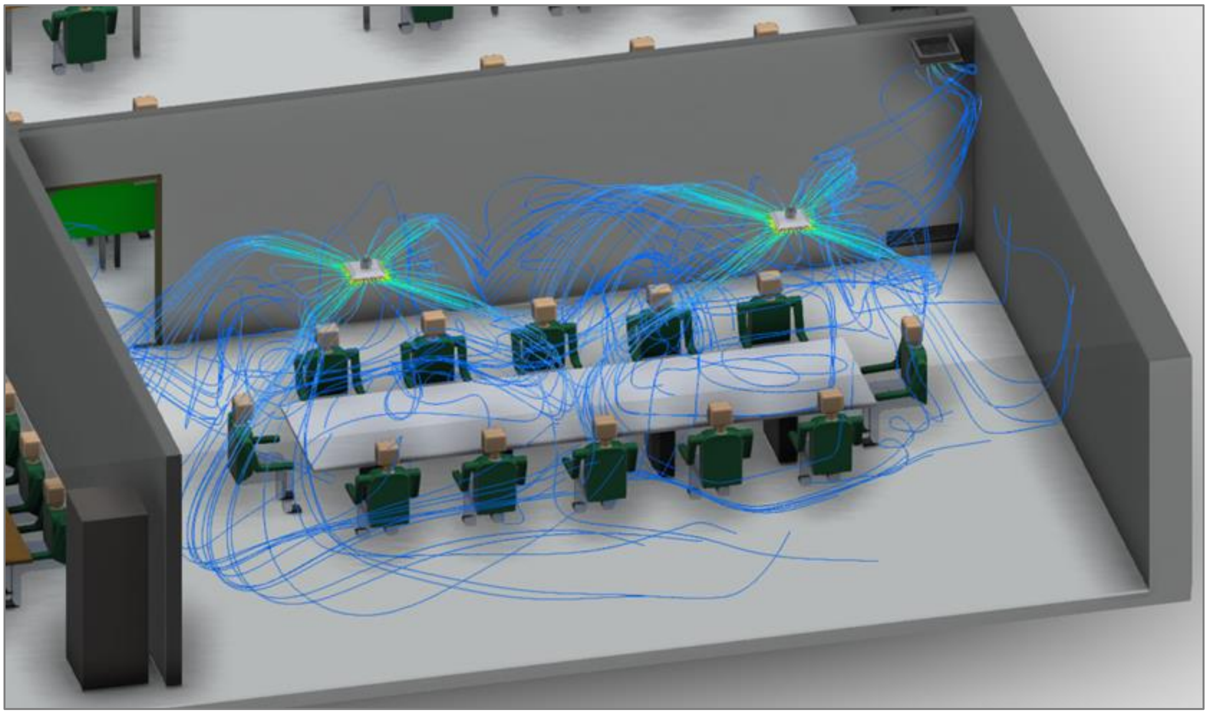
One challenge was generating real-time results by processing 3-5 gigabytes sized CFD simulation data. To solve this, simulation data is converted into a proprietary data format for satisfying fast I/O requirements. This enabled results like the cut section to be available to users in less than 30 sec, and complex comfort clouds can be visualized in nearly 2 mins.

Flowlines
Flow lines depict the path followed by conditioned air from a supply outlet into space till the return grill. Along with that path, the flow lines also display the magnitude of each particle's

velocity and temperature along its way. This is useful information to identify recirculation zones and draft in a space.

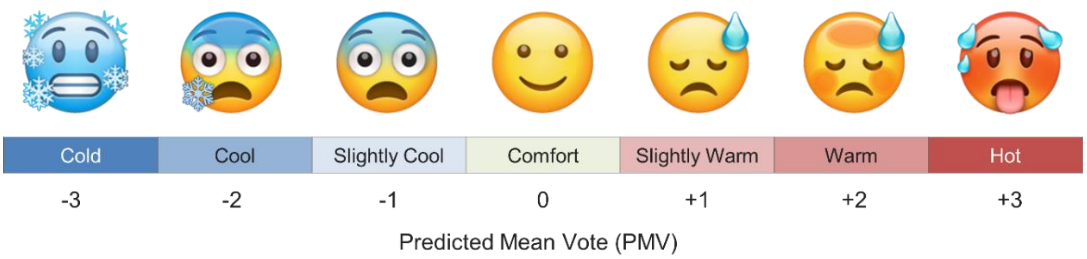


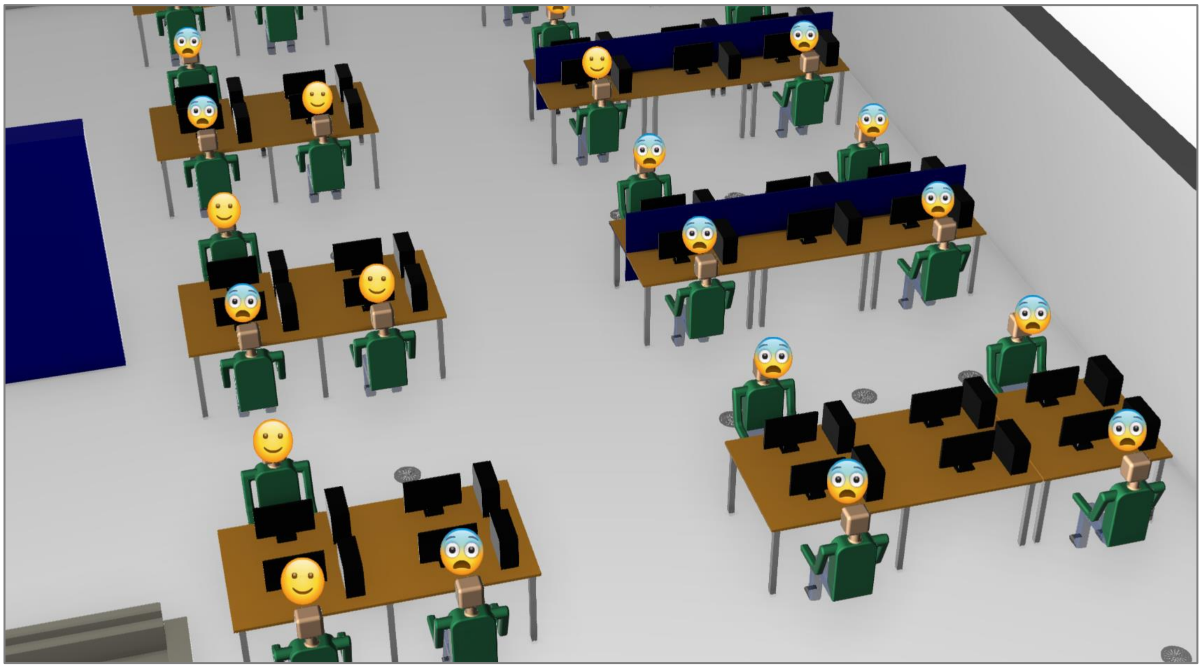
Flowlines from an Underfloor Diffuser



Flowlines from an Overhead Diffuser

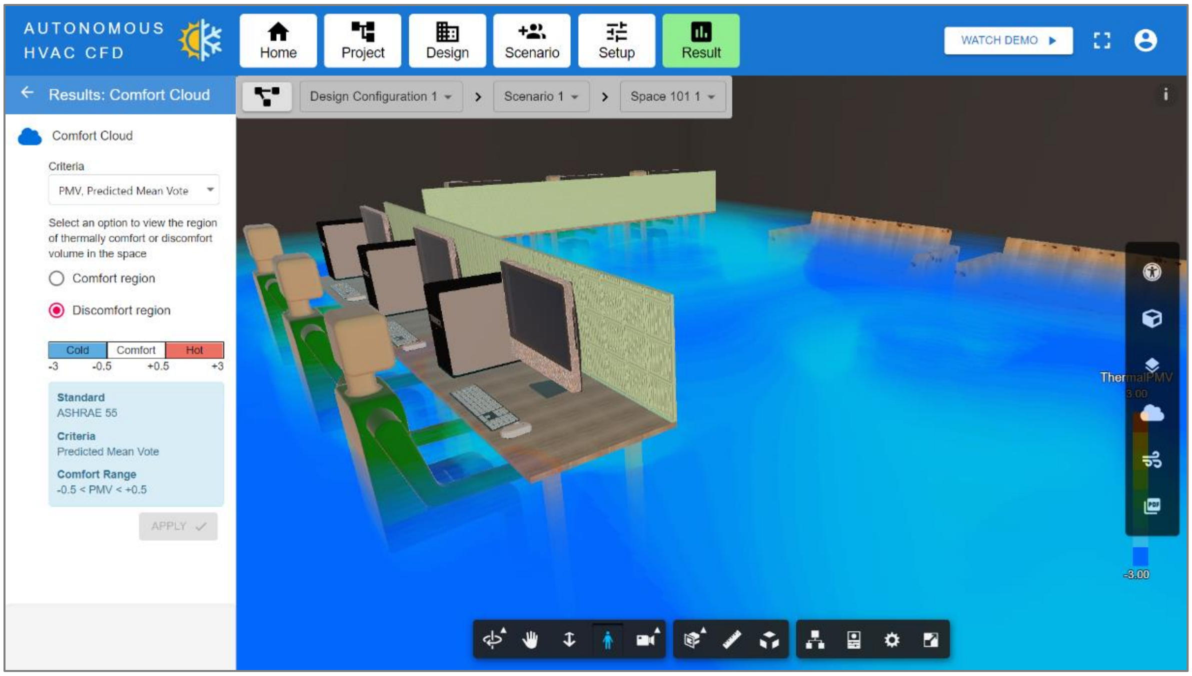
Thermal Comfort
Based on the average Predicted Mean Vote (PMV) on the manikin body surface, each manikin is rated with an emoji that expresses how they feel with respect to the thermal comfort scale.





Occupant thermal comfort sensation expressed with emoji representation over manikins

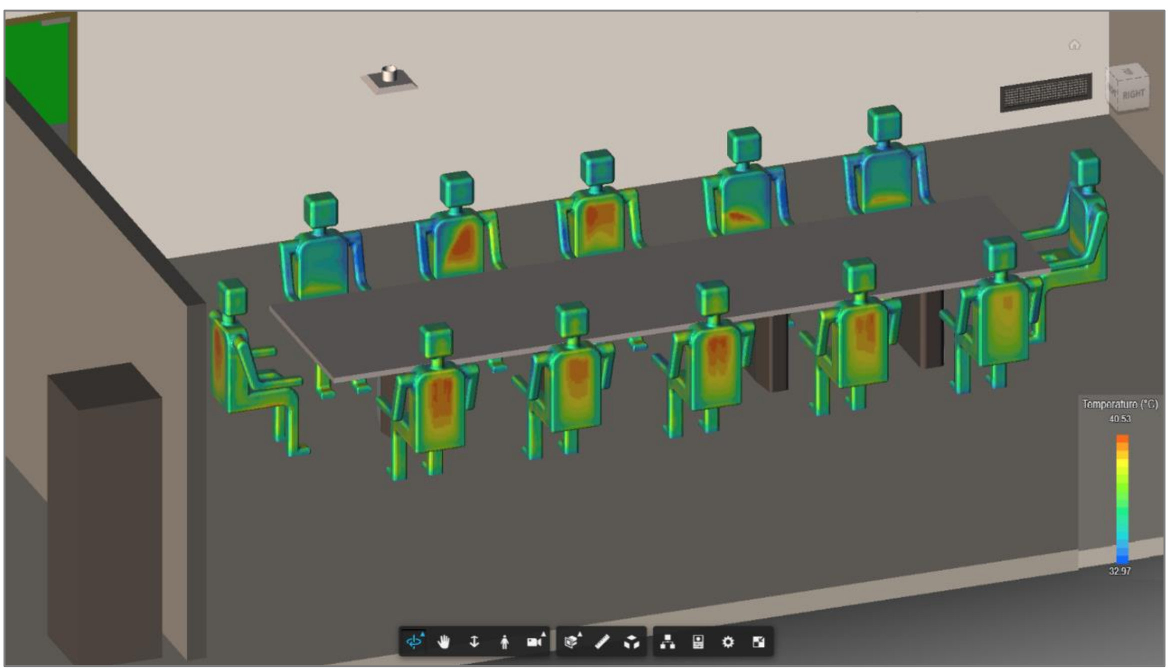
Comfort Cloud
Comfort cloud is the volume of a space that falls within a specified range of a result quantity value. This is popularly known as iso-volume in the CFD community. This data helps in finding out the hot & cold pockets in the space, comfort, and discomfort regions in the spaces.



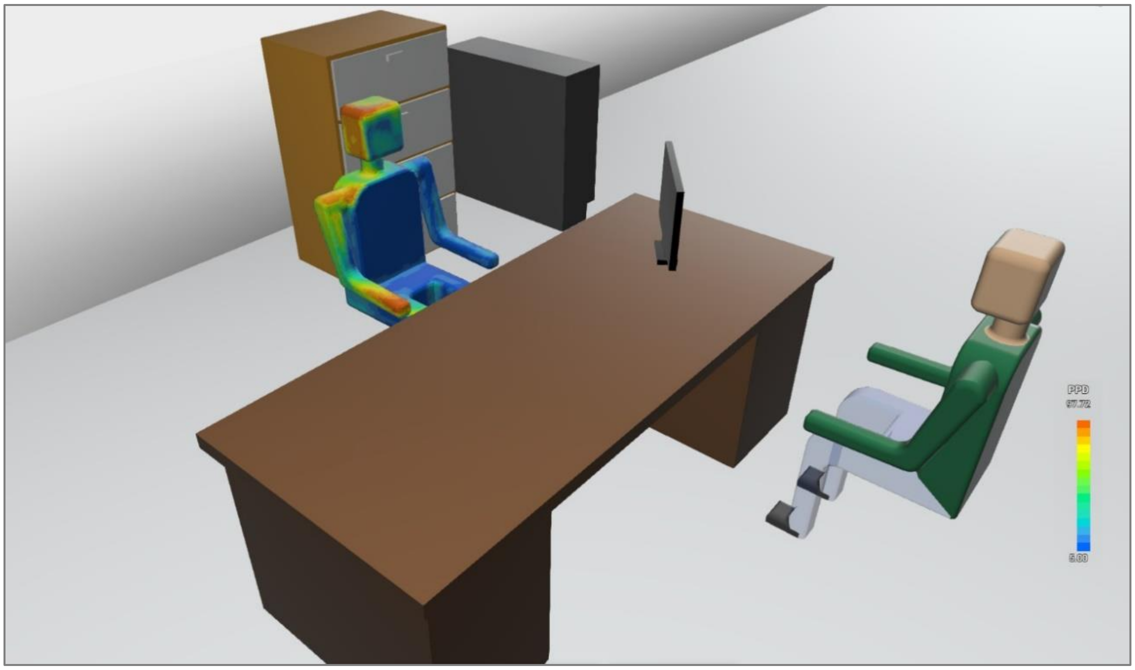
Comfort Cloud with PMV criteria

Surface Plots

Surface plots are contours of temperature, PMV, PPD plotted on the manikin surfaces. This information is useful to identify the regions of discomfort on the occupant body.



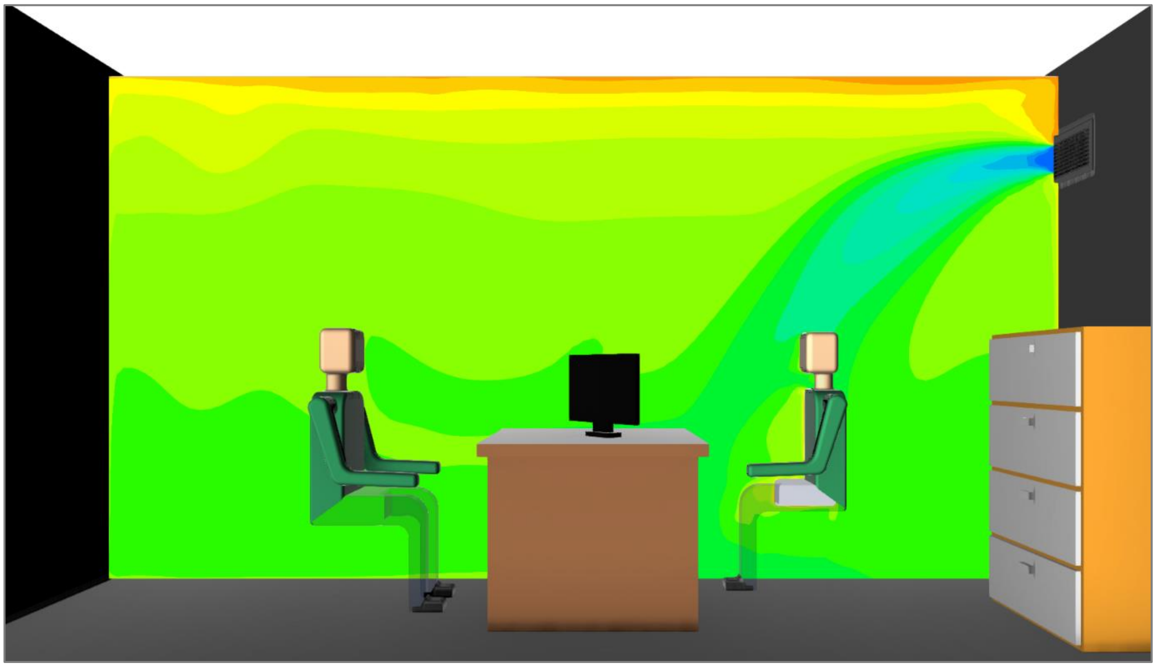
Manikin surfaces colored by Temperature



Manikin surface colored by PPD value

Contour Plots

Surface plots are contours of temperature, PMV, PPD plotted on the manikin surfaces. This information is useful to identify the regions of discomfort on the occupant body.

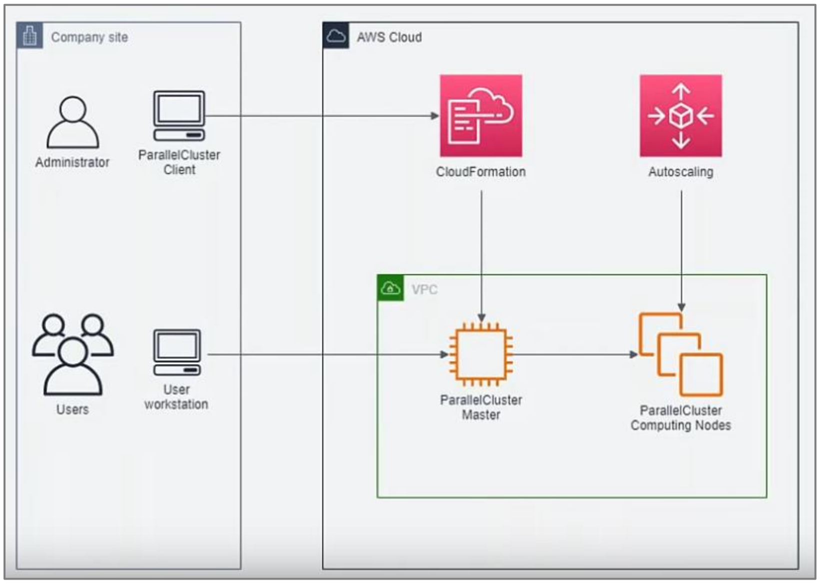


Cut section showing velocity contour plots

Assembling an AWS HPC Cluster for large HVAC CFD simulations

In HVAC applications, often the app must handle bigger indoor spaces like office bullpen areas, auditoriums, and large shopping malls. The mesh count in these cases can go more than 15million. Adding to the mesh count the solver uses computationally heave models like DOM, to capture the physics accurately. This type of CFD simulation requires large computational resources and generally takes around a few days to complete the simulations, and act as a bottleneck in the design iterations. Therefore, to remove this hurdle, the High-Performance Computing (HPC) Cluster support is provided in our application, which completes the simulations within 1 to 3 hours. The app manages to scale up or down the cloud capacity based on space size.

However, building and maintaining an HPC system is a complex process. Still, AWS created AWS ParallelCluster web service, which offers a simple method to create an automatically scaling HPC system in the AWS Cloud, utilizing services such as Amazon EC2, AWS Batch, Amazon FSx for Lustre, and Elastic Fabric Adapter. AWS Parallel Cluster configures the compute and storage resources necessary to run your HPC workloads. Settings based on your specific storage, compute, and network requirements all help optimize its functionality. A typical architecture of AWS Cluster is shown below figure.



A typical architecture of AWS ParallelCluster

However, having the HPC infrastructure is not sufficient. We need to take care of many factors to achieve the best performance and maintain a linear scale-up in the cluster to avoid wasting resources.

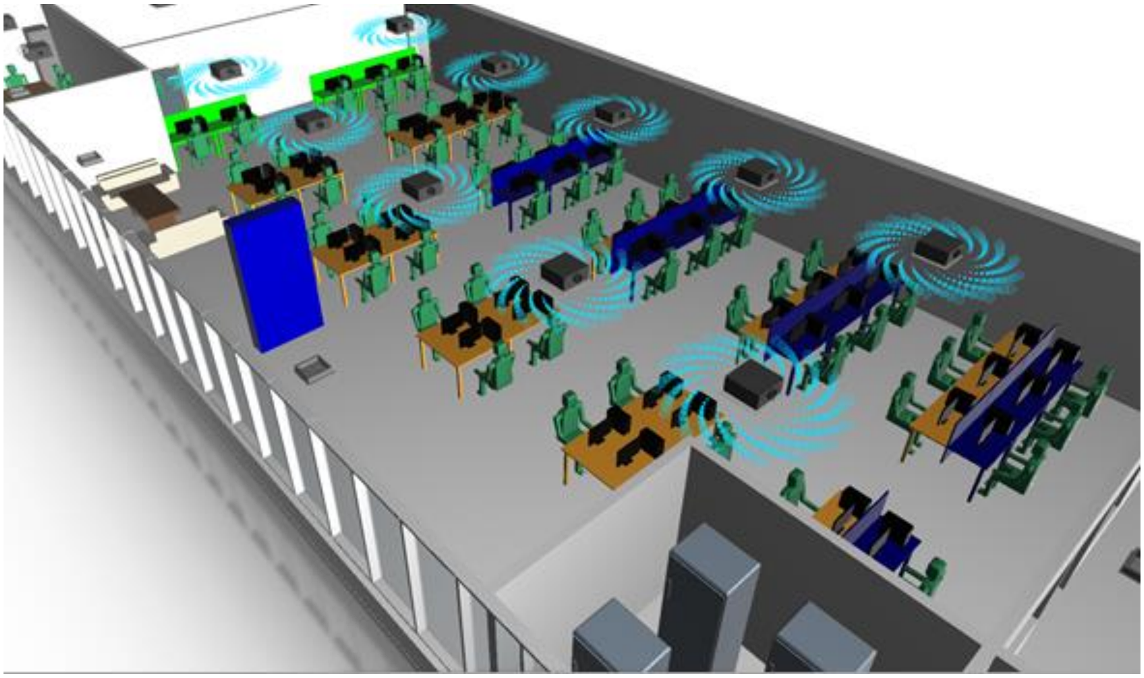
Such factors are:

- Selection of compute instance type and its combination
- Selection High-speed network for communication

- Selection of MPI type and mode of use
- Selection of job scheduler

From a CFD point of view, we decide the number of cells/core and the number of cores for a simulation.

Let's see how HPC helps to get the simulation result within less time with an example. We took a bigger space, i.e., our CCTech bullpen workspace shown in the below figure, which has a seating arrangement of 60 occupants.



CCTech Bullpen workspace – building model

The mesh count with our meshing strategy for this large space is about 6 Mn; with this high mesh count and capturing the physics mentioned above, the simulation becomes very computationally expensive. On a single 36 core AWS c4.8xlarge machine, the computational time is about 17.54 hours, which may be the bottleneck in designing HVAC systems. So, the simulation of bigger spaces on a single machine is not a viable option.

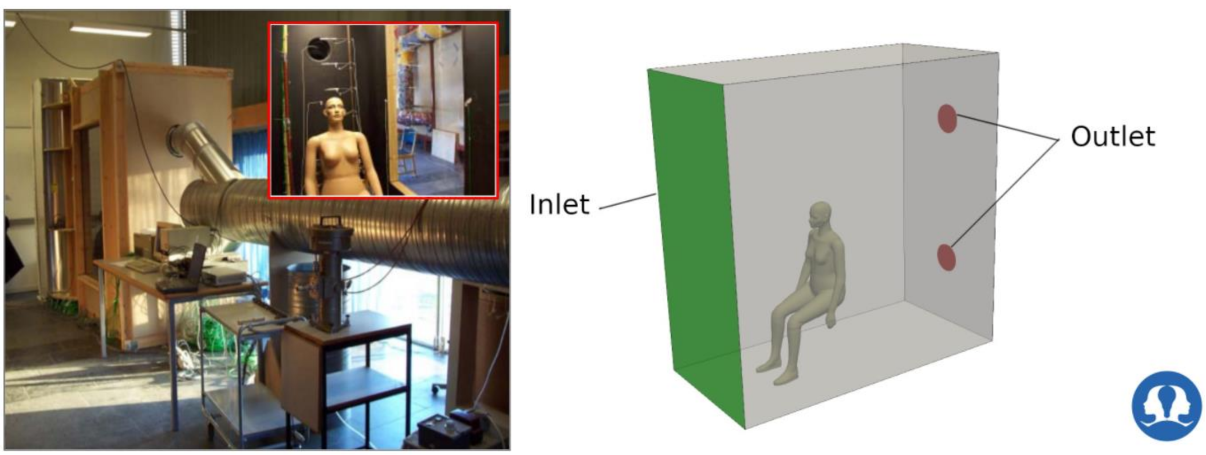
To overcome the time bottleneck and to intend to complete the simulation within hours, we performed a simulation on an AWS ParallelCluster of 216 cores (6 compute nodes with 1 smaller master node), which bring down the computational time to 2.71 hrs and shows that the use of a cluster gives a linear scale-up behavior. The 216 cores collection provides the performance scale-up about six times for almost twice the single machine's price.

Verification and Validation

Being autonomous is a great help, but it is also vital that the solution we are offering is reliable and accurate. Simulationhub Autonomous HVAC CFD application has automated the CFD analysis, which involves creating geometry models, meshing, and solving the physics for indoor rooms with HVAC systems. To achieve automation, we developed strategies like meshing and solving for CFD simulation dedicated to indoor spaces. These strategies were developed based on the observations from the multiple validation studies we did during the development of the application. One of the validation studies is explained here.

Benchmark test for Computer Simulated Person

We validated a standard benchmark case that has been developed by Nielsen et al. (P.V.Nielsen, S.Murakami, S.Kato, et al. "Benchmark test for Computer Simulated Person" Aalborg University, 2003) which has a seated thermal manikin inside a rectangular space to study the indoor environment. The air enters into space in front of the manikin and exits from two circular outlets at the back of the manikin as shown in the below figure. The thermal manikin is a non-breathing type & the heat flux from manikin was specified as a sensible heat load only.

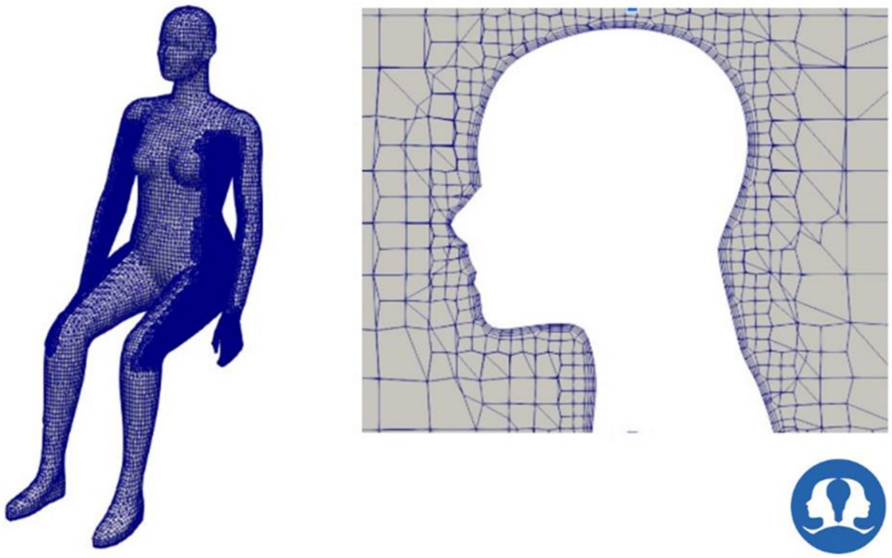


Test setup (left) and computational domain (right)

Image source

CFD Setup

As per the experimental setup, the fluid domain was generated with some approximation as shown in the figure. The mesh independence study was performed with different mesh sizes, and the optimal mesh size is selected in the current meshing strategy used in the app. The meshing is adequate enough to resolve the surface features and capture the flow and temperature field.

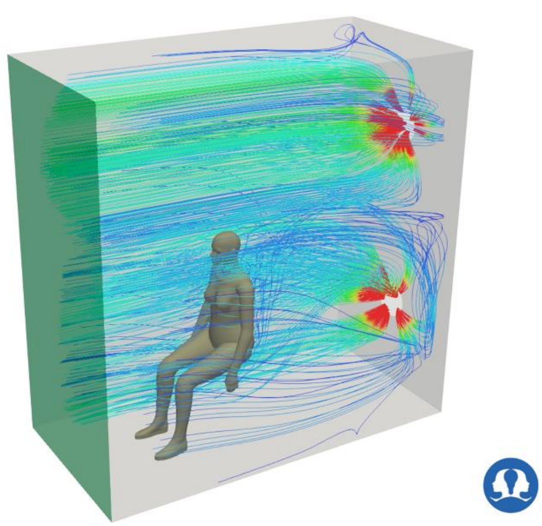


Mesh around ‘Comfortnia’ manikin - used in the CFD simulation

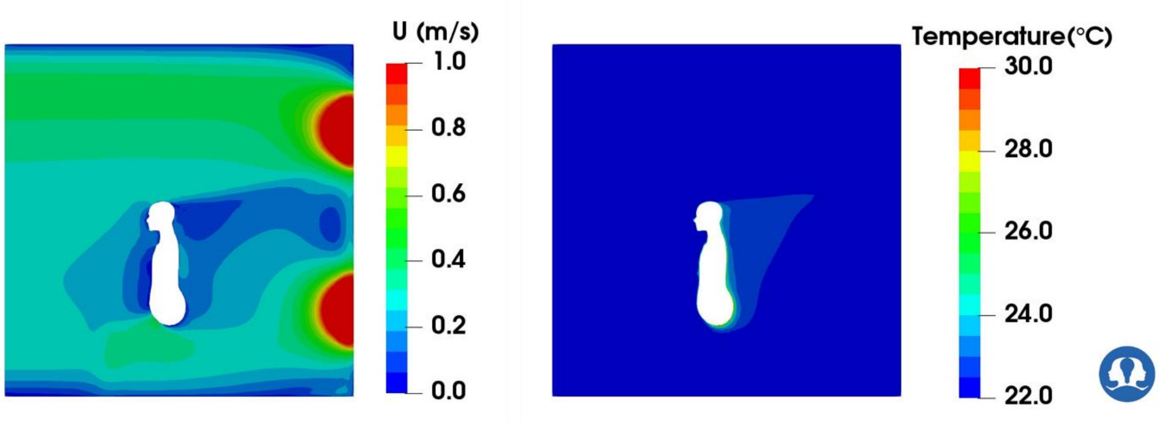
For the validation, the inlet velocity profile was modeled following the experimental values available downstream of the inlet. The manikin heat flux was 76 W (sensible heat load) as we would be considering convection and radiation. The SST k-ω turbulence model was used to capture the turbulence phenomenon. The residuals were set up to 10-6 along with monitors for the temperature flatness at critical locations for the convergence.

Result Validation

Following are the results obtained from the simulation:

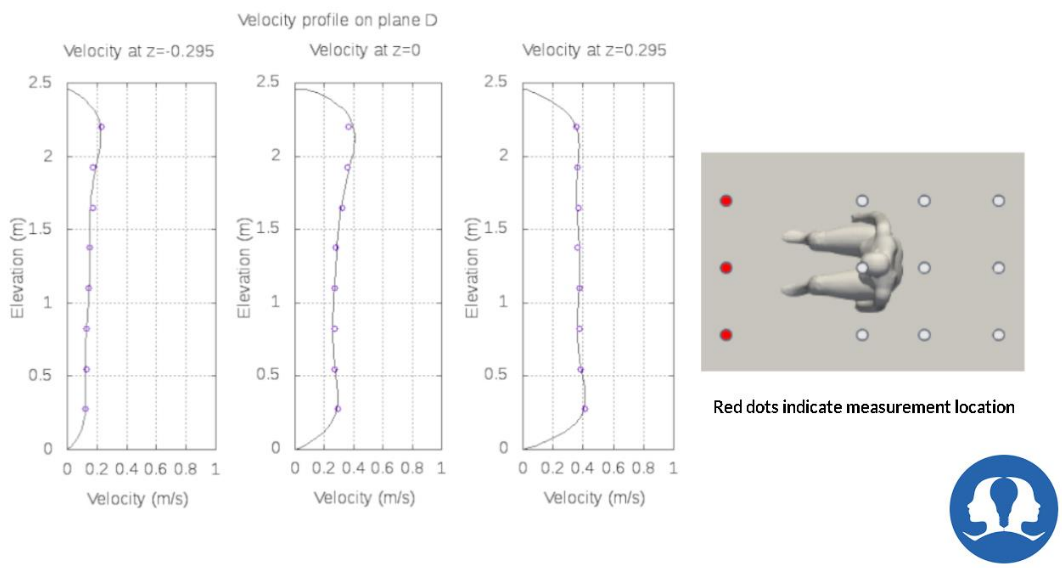


Flowlines from inlet plane

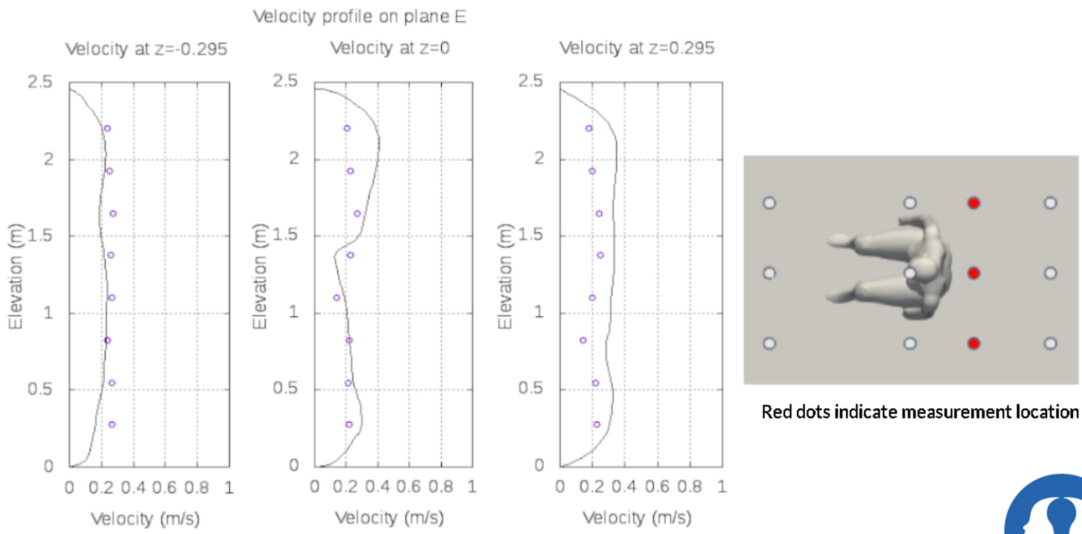


Velocity and Temperature contours at the midplane

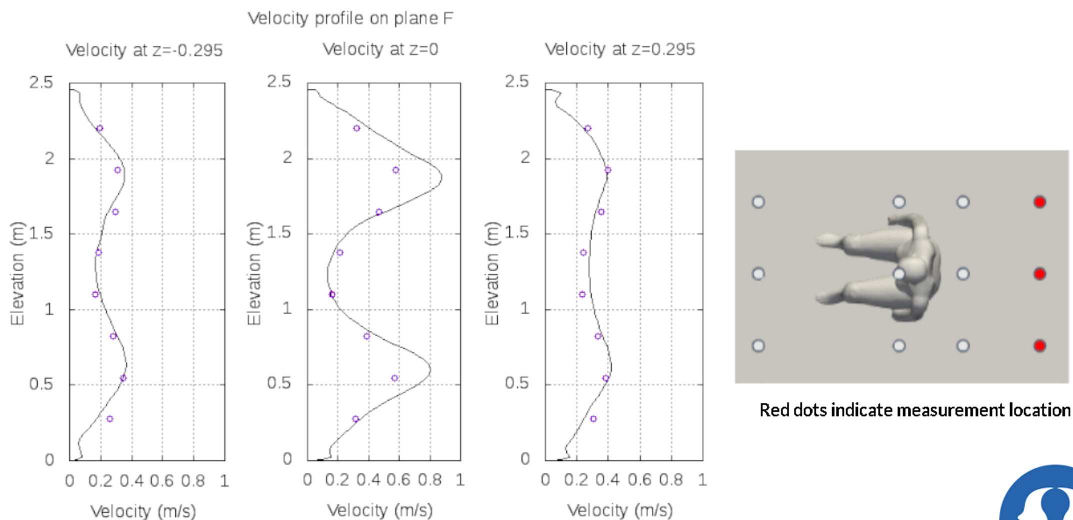
The velocity from the CFD analysis is compared with the experimental data available at the distinct points mentioned above.



Velocity profiles at plane D ('○': Experimental data, '—': CFD data)



Velocity profiles at plane E (‘○’: Experimental data, ‘—’: CFD data)



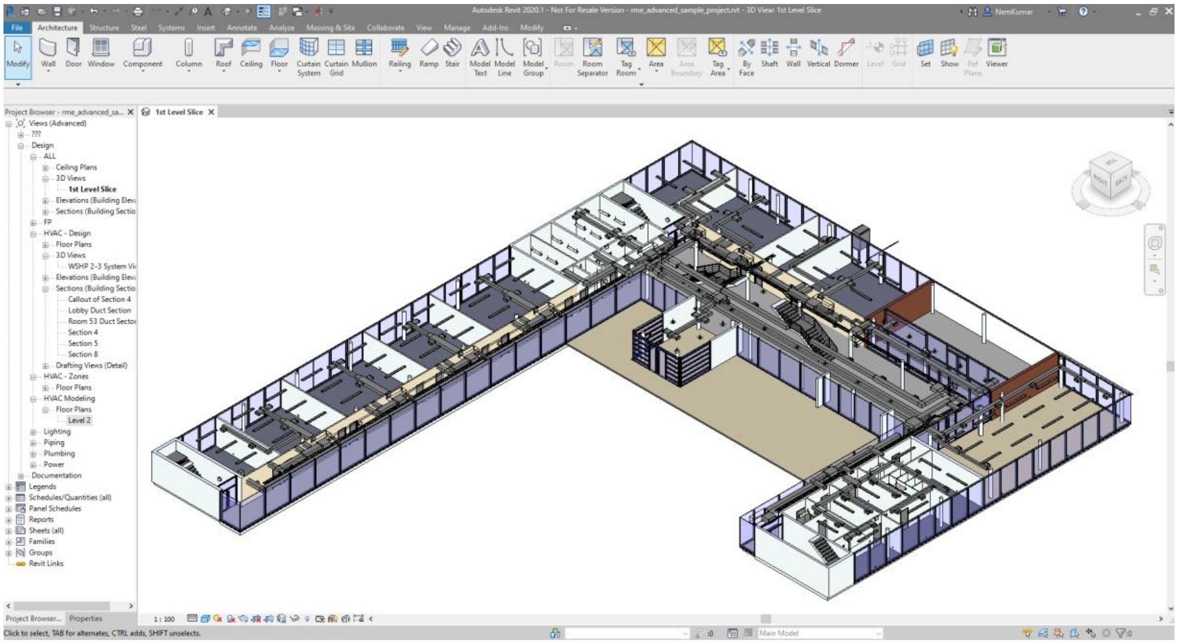
Velocity profiles at plane F (‘○’: Experimental data, ‘—’: CFD data)

For plane D, the velocity results from the CFD analysis are matching very closely with experimental results. The velocity values follow the trends of experimental velocity values with some deviation for plane E and F. The velocity at z=0 on plane F is slightly overshooting in CFD results compared to the experimental measurements. For all considered points on plane F (at the respective z values), the mean relative deviation is 4.47 %, while the standard deviation is

18.29% concerning experimental velocity values. The causes of variation can be attributed to the geometry differences between experimental and CFD study, inlet velocity profile, and heat flux distribution on the manikin.

From the above qualitative and quantitative comparisons of CFD results with experimental data, it is observed that our CFD results are in close agreement with the experiment. We developed the meshing and solving strategy more robust in our application through this type of validation studies.

Upcoming Plans and signup



BIM model of an office with HVAC system design in REVIT

Every application is as good as its current version. We are working on a server feature that will empower the HVAC community to use CFD even further.

- Revit data support
- Auto-generate 3D BIM model from uploaded 2d floor plan image or a drawing
- Building the Air diffuser manufacturers co-marketing space to add BIM components of product library
- Build the large public space templates such as Airports, Auditorium, Indoor stadium.
- Develop new Air quality indices – CO_2 concentration, Contaminant, Odor tracking, ADPI

We would like to invite you to our private beta of the AHC app. Please signup to explore the app:

https://www.simulationhub.com/autonomous-hvac-cfd-private-beta