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Automating the Two-Dimensional Design of Heating, Ventilation, Air Conditioning, and Refrigeration (HVACR) Ducts using Computer Programming Language: An Algorithmic Approach

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Abstract

This paper reports on designing an automated two-dimensional duct of Heating, Ventilation, Air Conditioning and Refrigeration (HVACR) using computer programming. The designed system uses an algorithmic approach attempting to accelerate the design process, decrease the human error of the designers and make the process of designing HVACR systems more efficient. It applies a system of interacting algorithms to solve duct sizing, routing and layout optimisation tasks. This facilitates both the saving of time and the increment of accuracy and consistency in the final design. By applying advanced computational techniques, it could analyse complex geometries of buildings and easily produce optimised designs for ducts. This research contributes to the field of HVACR engineering by providing a practical solution for automating a critical design phase. The automation system may be configured to work with existing Computer Aided Design (CAD) software, allowing for close collaboration between designers and engineers.

***Major Findings:** A computer program using Hyper Text Markup Language (HTML), Cascading Style Sheets (CSS) and JAVA allows for quick and accurate determination of duct size by applying standard empirical formulas that relate height, width, and diameter. The programmer can effortlessly adjust the design by simply modifying the input data and tailoring the duct specifications to meet specific requirements.*

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Keywords: *2-D Design, Air Conditioning, Computer Programming, Heating, HVACR, Optimisation Algorithms, Ventilation*

1.0 Introduction

1.1 Origin of Study

Variable Refrigerant Flow (VRF) systems utilise a single external unit connected to multiple indoor units. These systems are favoured for several reasons. They occupy less outdoor space compared to traditional central air conditioning systems, they are less invasive to install in existing, occupied buildings and they can simultaneously cool and heat through shared pipework. Unlike conventional hydraulic systems that use chilled or hot water circulated by pumps, VRF systems use refrigerant as the medium for cooling and heating[1]. VRF systems offer a flexible and efficient solution for heating and cooling multiple zones within a building. Unlike traditional Heating Ventilation and Air Conditioning (HVAC) systems that rely on ductwork to distribute conditioned air, VRF systems directly transport heating or cooling energy to individual indoor units using refrigerant. While VRF systems as shown in Figure 1 are often referred to as ductless, they may still incorporate ducts for certain applications, such as connecting indoor units, airing out spaces, soundproofing, Outdoor Units (OU), Indoor Units (IDU), refrigerant piping, Electronic Expansion Valve (EEV). By eliminating the need for extensive ductwork, VRF systems provide numerous benefits, including energy efficiency, precise temperature control, quiet operation and improved indoor air quality.

Overall, VRF systems offer flexibility and efficiency compared to traditional HVAC systems. However, they may still utilise ductwork for specific functions such as ventilation, air distribution, and indoor air quality management. The particular design and layout of ductwork in a VRF system will depend on factors such as building size, layout and usage requirements.

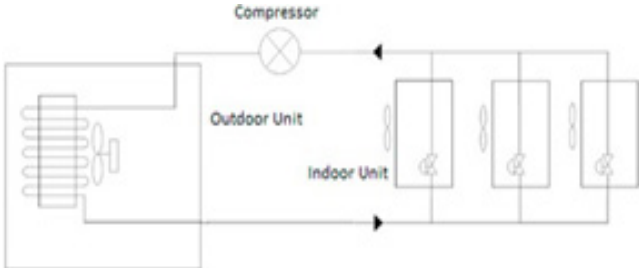


Figure 1. Schematic diagram of variable refrigerant flow[1].

This paper aims to design and document a detailed Plan and Elevation [2D] Drawing and a comprehensive Bill of Material (BOM) specifically for ducted VRF IDUs. The goal is to provide a clear visual representation of the ductwork layout and an exhaustive list of materials required for installation.

The project will prioritise efficiency, functionality, regulatory compliance, cost-effectiveness and compatibility with VRF IDUs. Collaborating closely with HVAC engineers, architects, contractors and stakeholders, will ensure a coherent and optimised design that aligns with industry standards and specific project requirements.

Through meticulous planning, accurate drawings and a detailed BOM, this project aims to lay the foundation for a seamlessly integrated ducting system, optimising the performance and efficiency of the overall VRF HVAC system while adhering to safety standards and cost considerations.

1.2 Objective of the Study

The main objectives of this research are

1. To create detailed 2D plans and elevations that accurately represent the layout and placement of ducting in conjunction with VRF IDUs.
2. To develop a comprehensive BOM, detailing the materials required for the ducting system, including dimensions, quantities and specifications.
3. Provide the drawings and BOM in formats compatible with industry-standard design and construction software for seamless integration into project workflows.

Automated duct design significantly improves efficiency and accuracy. By streamlining the process, it reduces time spent on manual design and documentation. Additionally, it enables more precise calculations and predictions, leading to optimised duct systems.

2.0 Review of Literature

VRF systems have gained significant popularity in recent

years due to their energy efficiency and flexibility. These systems offer precise temperature control for individual rooms or zones, making them ideal for both residential and commercial applications. Several studies have explored various aspects of VRF systems.

2.1 Performance Optimisation

Climate-Specific Design: Mingyang Qian *et al.*,[2] highlighted the importance of tailoring VRF system designs to specific climatic conditions to maximize performance.

Insulation Thickness: Abdullah Yildiz *et al.*,[3] and Mohammed Abujab *et al.*,[4] investigated the impact of insulation on energy consumption and identified optimal thicknesses for different pipe diameters and materials.

Control Strategies: Mutasher[5] emphasised the significance of controllability in VRF systems, as it allows for precise adjustments to meet varying space load demands.

2.2 Energy Efficiency

Comparative Analysis: Tolga N. Aynur *et al.*,[6] compared VRF and Variable Air Volume (VAV) systems and found that VRF systems offer significant energy savings, particularly in part-load conditions.

Water-Cooled VRF Systems: Yueming Li *et al.*,[7] studied the performance of water-cooled VRF systems and identified potential efficiency gains, especially in part-load conditions.

Tropical Climate Applications: Y. H. Yau and M. Amir[8] demonstrated the suitability of VRF systems for tropical climates, highlighting their energy-saving potential and economic feasibility.

2.3 Performance Evaluation

Virtual Sensor Models: M. Qian *et al*,[9] utilised virtual sensor models to assess the performance of VRF systems and identify factors influencing energy consumption and efficiency.

Compressor Volumetric Efficiency: Naruhiro Sekine *et al.*,[10] developed a method to evaluate VRF system performance based on compressor volumetric efficiency, providing accurate capacity estimations.

2.4 Duct Design Considerations

Effective duct design is crucial for optimising the performance of HVAC systems, including VRF systems. Several studies have focused on duct design techniques and optimisation:

Modelling Techniques: Bryan P Rasmussen *et al.*,[11] compared FCV and MB modelling techniques for VCC systems, highlighting the trade-offs between complexity and accuracy.

Low-Load House Design: Arlan Burdick[12] addressed the challenges of air outlet sizing in low-load houses and emphasised the importance of careful air distribution and duct design to ensure comfort.

Duct Sizing and Optimisation: Annapu Reddy Sambasiva Rao *et al.*,[13] and Kumar BP *et al.*,[14] used the equal friction method to design duct systems with minimal pressure loss, optimising duct sizes and shapes.

CFD Simulations: Vishal Shah *et al.*,[15] employed CFD simulations to compare circular and rectangular duct systems, demonstrating the advantages of circular ducts in terms of reduced pressure drop and turbulence.

In conclusion, VRF systems offer significant energy efficiency and flexibility, making them a popular choice for HVAC applications. Effective design and optimisation, including careful consideration of factors such as insulation, control strategies and duct design, are essential to maximise their benefits. By leveraging the insights from the studies reviewed, engineers and designers can implement best practices to achieve optimal performance and energy savings. Kurhade *et.al.*,[16-18] elaborate on the different materials and their effects in different conditions.

3.0 Languages and Technologies Adopted

3.1 Hypertext Markup Language

It is the standard language for structuring and organising content on web pages. HTML defines both layout and content about which components such as headings, paragraphs, images, links, etc, are rendered in what way. Unlike programming languages, HTML is a markup language that uses tags describing the structure of a web page.

Key Components:

- Tags: HTML uses tags to define different elements within a document. Tags are enclosed in angle brackets (<>). They typically come in pairs: an opening tag (<tag>) and a closing tag (</tag>). Some tags, like <br /> for a line break, are self-closing.
- Attributes: Tags can have attributes that provide additional information. Attributes appear within the opening tag and are written as name-value pairs, like name="value". For example, Link uses the href attribute to specify the link's destination.
- Elements: Elements are formed by tags and their content. They define the structure and content of the web page. For instance, a heading element might look like this: <h1>This is a Heading</h1>. Basic Structure:

A simple HTML document structure includes:

```HTML
<!DOCTYPE html>
<html>
<head>
<title>Title of the Page</title>
</head>
<body>
<!-- Content of the web page -->
<h1>Main Heading</h1>
<p>Paragraph of text.</p>
</body>
</html>
```

- `<!DOCTYPE html>`: Declares the document type and version of HTML used.
- `<html>`: Wraps the entire HTML content.
- `<head>`: Contains meta-information about the document (e.g., title, links to stylesheets, scripts).
- `<title>`: Sets the title of the web page displayed in the browser tab.
- `<body>`: Contains the visible content of the web page (text, images, links, etc.).

By creating the HTML form, we can easily get the required data from the customer.

3.2 Cascading Style Sheets

CSS (Cascading Style Sheets) is a language used to style the appearance of web pages written in HTML or XML. It enables developers to control the layout, colours, fonts and other visual aspects of their websites. CSS works by selecting HTML elements and applying styles to them using selectors and properties. Styles can be defined directly within HTML documents or in separate CSS files, offering flexibility and reusability. CSS follows a cascading hierarchy, where styles can be inherited from parent elements or overridden by more specific rules. By using CSS, developers can create visually appealing and consistent designs across their websites, enhancing the user experience.

Coding of Case

```
form {
margin: 20px; padding: 20px;
background-color: #f0f0f0; border-radius: 10px;
}
label {
display: block; margin-bottom: 5px;
}
input {
width: 100%; padding: 10px; margin-bottom: 10px;
border-radius: 5px;
border: 1px solid #ccc;

}
button {
padding: 10px 20px; background-color: #007bff; color: #fff;
border: none; border-radius: 5px; cursor: pointer;
}
button: hover {
```

background-color: #0056b3;

}

1. Form Styles

`margin: 20px;`: Adds 20 pixels of space outside the form, creating a margin around it.

`padding: 20px;`: Adds 20 pixels of space inside the form, creating padding around its content.

`background-colour: #f0f0f0;`: Sets the background colour of the form to a light grey.

`border-radius: 10px;`: Rounds the corners of the form, giving it a softer appearance.

2. Label Styles

`display: block;`: Configures labels to display as block elements, ensuring they start on a new line.

`margin-bottom: 5px;`: Adds 5 pixels of space below each label, creating vertical spacing between them.

3. Input Styles

`width: 100%;`: Makes input fields stretch to 100% of their parent container's width.

`padding: 10px;`: Adds 10 pixels of padding inside each input field.

`margin-bottom: 10px;`: Adds 10 pixels of space below each input field, creating vertical spacing between them.

`border-radius: 5px;`: Rounds the corners of the input fields.

`border: 1px solid #ccc;`: Sets a 1-pixel solid border around each input field, with a light grey colour.

4. Button Styles

`padding: 10px 20px;`: Adds 10 pixels of padding on the top and bottom, and 20 pixels on the left and right, inside each button.

`background-colour: #007bff;`: Sets the background colour of the buttons to a shade of blue.

`colour: #fff;`: Sets the text colour of the buttons to white.

`border: none;`: Removes the border around the buttons.

`border-radius: 5px;`: Rounds the corners of the buttons.

`cursor: pointer;`: Changes the cursor to a pointer when hovering over the buttons, indicating they are clickable.

5. Button Hover Effect

`button: hover`: Applies styles to buttons when hovered over by the mouse.

`background-colour: #0056b3;`: Changes the background colour of the buttons to a darker shade of blue when hovered over, providing visual feedback to the user.

3.3 Java Script

JavaScript is a versatile programming language widely used in web development to add interactivity and dynamic behaviour to web pages. It runs directly in web browsers, enabling developers to manipulate HTML and CSS, respond to user actions, and create responsive, feature-rich web applications. JavaScript can perform tasks like form validation, Document Object Model (DOM) manipulation and event handling Asynchronous Javascript and XML (AJAX) requests, allowing for the creation of interactive user interfaces. Its widespread adoption and extensive ecosystem of libraries and frameworks make JavaScript indispensable for building modern web applications that provide a seamless and engaging user experience.

Basic example -

document.querySelector ('form'). add Event Listener ('submit', function(event) { const username Input = document.get Element By Id('username');

const password Input = document.get Element By Id('password');

if (username Input.value.trim() === '' || password Input. value.trim() === '') { event.prevent Default(); alert('Please fill in all fields.');

}

});

1. Event Listener Registration

`document.querySelector ('form'). add Event Listener ('submit', function(event) {`: This line selects the first `` element found in the document and attaches an event

listener for the submit event. When the form is submitted (e.g., by clicking a submit button or pressing Enter while focused on an input field), the provided function is called.

2. Form Input Retrieval

`const username Input = document.get Element By Id('username');`: Retrieves the input element with the id "username" from the form.

`const password Input = document.get Element By Id ('password');`: Retrieves the input element with the id "password" from the form.

3. Form Validation

`if (username Input.value.trim () === '' || password Input. value.trim () === '') {`: Checks if either the username or password input fields are empty after trimming any leading or trailing whitespace.

`event.prevent Default();`: Prevents the default action of form submission if any of the input fields are empty. This prevents the form from being submitted to the server.

`alert ('Please fill in all fields.');`: Displays an alert message informing the user to fill in all fields if any of the input fields are empty.

4. Event Handling

`function (event) { ... }`: Defines an anonymous function that takes an event object as its parameter. The function is executed when the form is submitted.

`event parameter: Represents the submitted event object. It contains information about the event, such as the form being submitted.

3.4 Scalable Vector Graphics

Scalable Vector Graphics (SVG), is a way to create images using text instructions. It's like drawing with shapes and lines, similar to how you might draw with a pen on paper. The special thing about SVG is that the images you make can be resized without losing quality, just like when you zoom in or out on a photo on your phone. People use SVG for things like logos, icons and illustrations on websites because they look sharp and clear on any screen size.

Calculation of Duct Design:

i. Converting Air Flow to m^3/s:

Air Flow Per Second = Air Flow/3600

ii. Calculating Duct Area:

Duct Area = Air Flow Per Second /Air Velocity

iii. Calculating Height Using Aspect Ratio Height =√Aspect Ratio / Duct Area

iv. Calculating Width Using Aspect Ratio :

Width = Aspect Ratio * Height Bill Of Material

i. Calculating BOM

BOM= Perimeter * Length

∴ BOM= 2*(width + height) * Length

Note: Here the BOM is calculated for the quantity of material required for ducting and not inclusive of price as it varies from place to place.

4.0 Experimental Results

Three distinct case studies are presented to justify the output generated by the developed program. Figure 2 provides a detailed overview, with Part A focusing on the input data for the room where the duct system is to

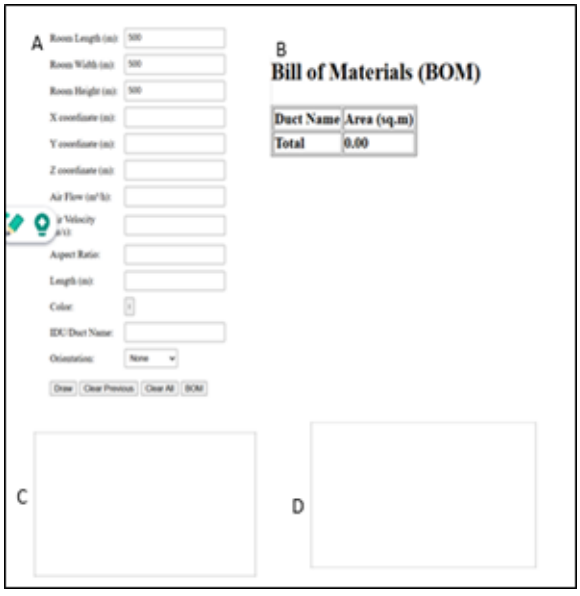


Figure 2. Development of compiled reports through software.

be designed. This section includes the key dimensions and parameters required for the design process. Part B elaborates on the bill of materials, which outlines the duct's specifications, including the area calculations.

Case Study -1

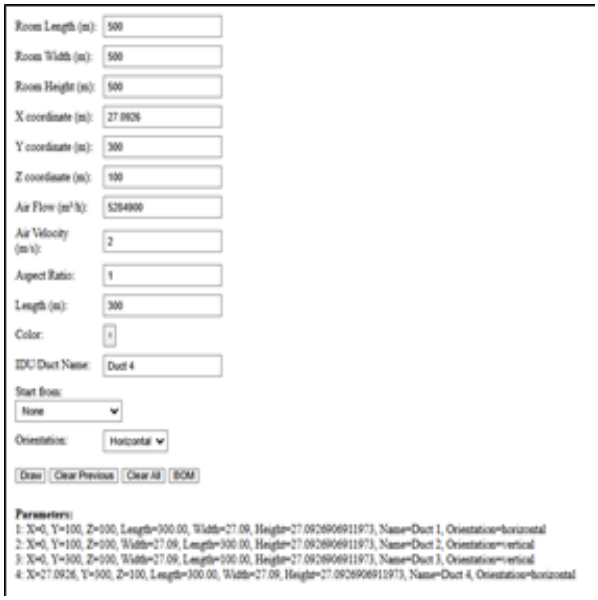


Figure 3(A). Customer requirements (Input data to the software).

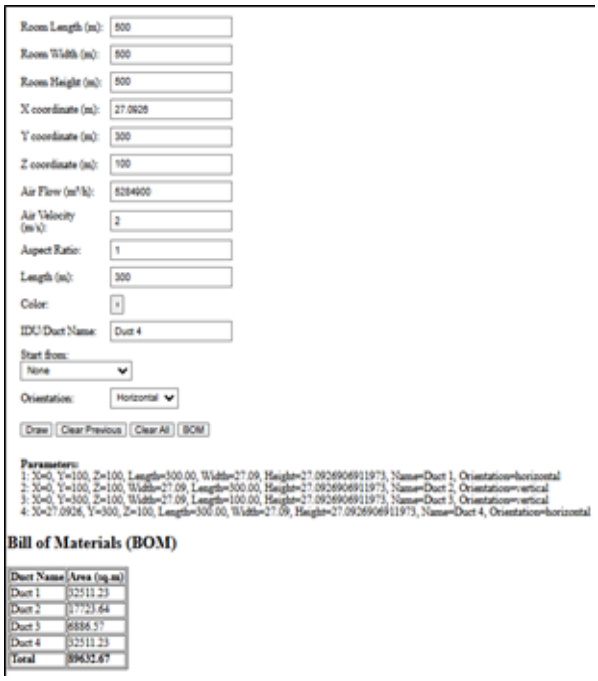


Figure 3(B). Bill of materials.

These calculations are based on empirical relationships discussed in Section 3.5 and are processed using the software. This ensures that the duct design is both accurate and reliable. The final section of the figure presents both the plan view (top view) and the elevation view of the duct, providing a comprehensive visual representation of the design. These views help in understanding the spatial arrangement and dimensions of the duct system within the room. It is important to note that the pattern followed in these case studies remains consistent across all three examples, ensuring a standardised approach to the design



Figure 3(C) and (D). Plan view and elevated view of duct design.

Case Study -2

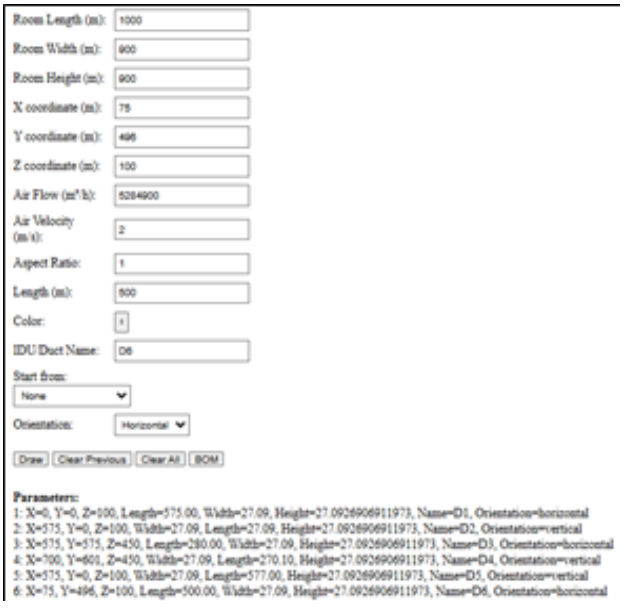


Figure 4(A). Customer requirements (Input data to the software).

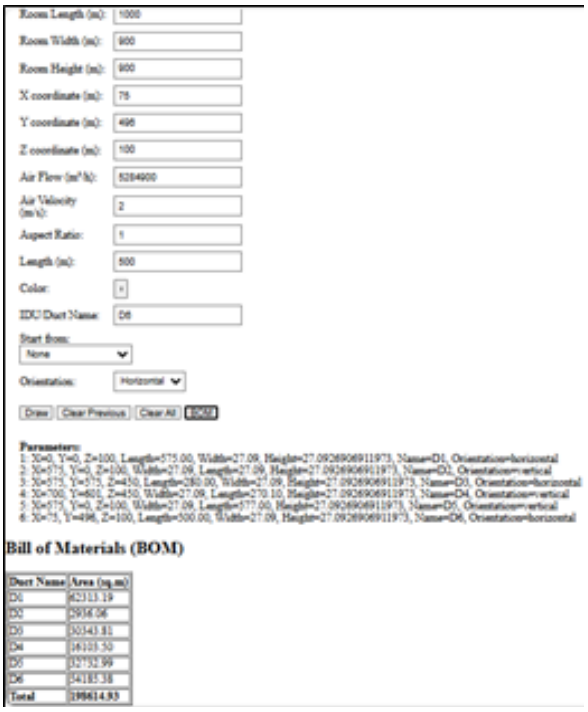


Figure 4(B). Bill of materials.



Figure 4(C) and (D). Plan view and elevated view of duct design.

and validation of the duct systems. Each case study uses the same methodology to demonstrate the program's capability to generate accurate and consistent outputs for duct design.

Figure 2A shows the parameter form. It includes details like dimensions of the territory/room in which ducting is needed, the starting point of the duct concerning the room, the airflow in m^3/hr, air velocity, aspect ratio, and length of the duct. It also has options to select the colour of each duct and the duct name or text to be displayed on the said duct for ease of understanding. After filling out the form, when clicked on draw new tabs showing plan and elevation view respectively as shown in

Case Study -3

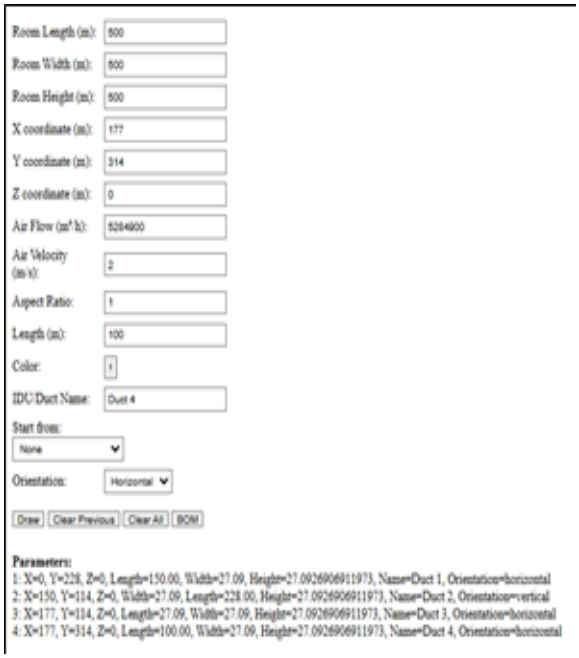


Figure 5(A). Customer requirements (Input data to the software).

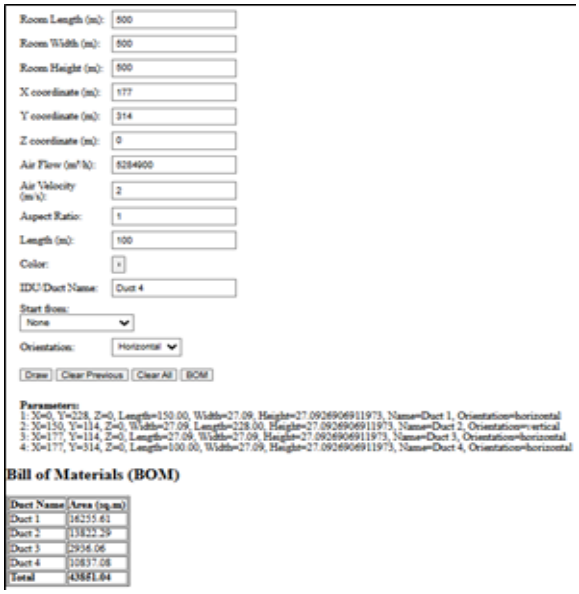


Figure 5(B). Bill of materials.

Figure 3(C), 4(C), 5(C) and Figure 3(D), 4(D) and 5(D) open up. When clicked on the BOM tab the bill of the material tab as shown in Figures 3(B), 4(B) and 5(D) opens.

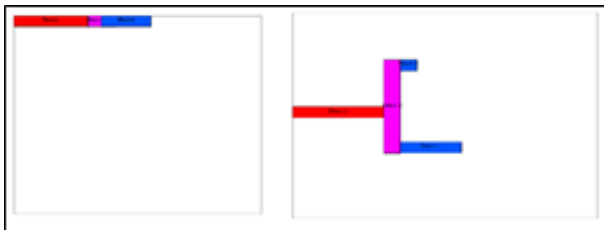


Figure 5(C) and (D). Plan view and elevated view of duct design.

5.0 Conclusion

This paper will introduce a comprehensive approach to the design and documentation of ducting systems for construction projects that require ducted VRF Indoor Units IDUs. The 2D drawings provided are both plan and elevation views, which will provide a clear and accurate view of the ductwork layout within the building. A comprehensive BOM that contains all the necessary parts and materials, along with specifications, is included in the document package. It is created with seamless integration into project workflows and compatibility with industry-standard design software, which can help to enhance coordination, communication and decision-making for the project. It finally serves as a valuable tool for users who are accessing the HTML page.

6.0 Acknowledgement

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