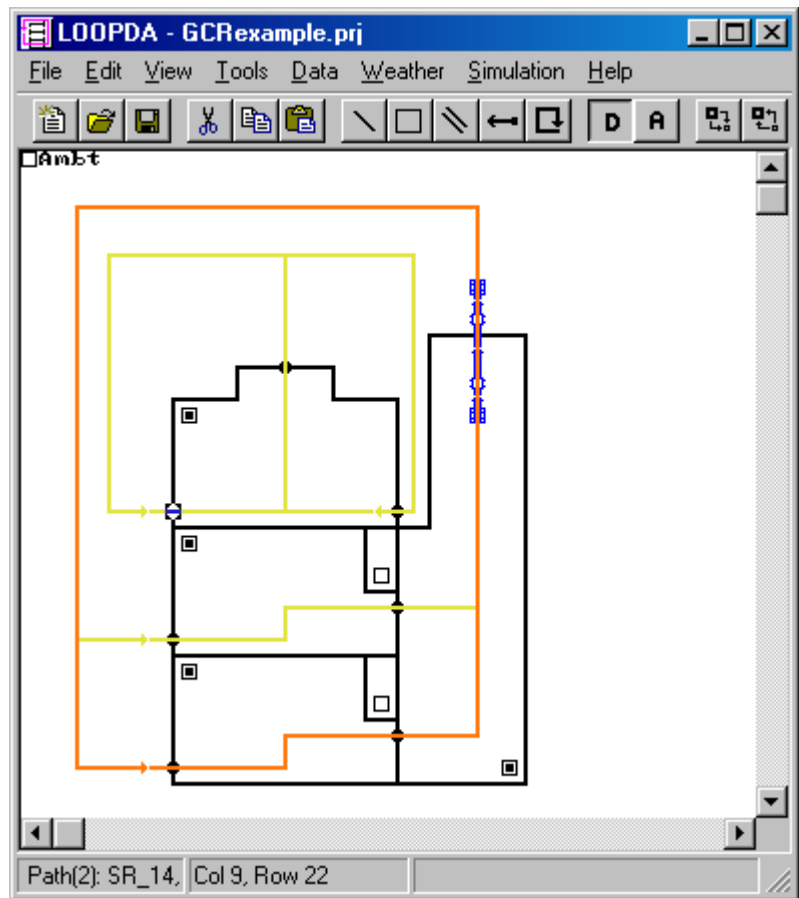


LoopDA – Natural Ventilation Design and Analysis Software

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Analysis Software**

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ABSTRACT

The *Loop Equation Design Method* has been proposed for sizing ventilation airflow components of natural and hybrid ventilation systems. While the approach has been demonstrated on a limited basis, the method has been automated in order to better evaluate its reliability under a more controlled, i.e., less error-prone, environment. This report describes a computer program developed by NIST that implements the *Loop Equation Design Method* of sizing the openings of naturally ventilated buildings. The tool, referred to as *LoopDA* for Loop Design and Analysis, is integrated with an existing multi-zone analysis tool CONTAMW. LoopDA provides the designer of natural ventilation systems with an environment in which to perform and document the process of designing the opening sizes of natural ventilation systems and analyzing the system behavior under a variety of operating conditions. This report describes the first version of the LoopDA program, provides an example of its application to the design of a naturally ventilated building and describes needs for future enhancements to the tool to increase its usefulness within the design community.

Key Words: airflow analysis; building technology; computer program; design tool; indoor air quality; multizone analysis; natural ventilation

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Table of Contents

Abstract.....	iii
Software Disclaimer.....	iv
1 Introduction.....	1
2 Loop Equation Design Method.....	2
3 The LoopDA Software Tool.....	3
3.1 Installing and Running LoopDA.....	4
3.2 Basic Approach to Design Using LoopDA.....	5
3.3 Working with LoopDA.....	6
4 Design Example using LoopDA.....	18
4.1 Sample Building.....	18
4.2 Design Conditions and Criteria.....	18
4.3 Pressure Loops.....	20
5 Conclusion.....	29
6 References.....	30
7 Acknowledgments.....	31

1 INTRODUCTION

NIST is investigating the application of state-of-the-art natural ventilation concepts in small commercial buildings in California and developing design methods for natural ventilation in new and retrofit applications. An earlier report [1] reviewed the application of natural ventilation in commercial buildings including the associated technology, potential advantages of natural ventilation and issues that need to be addressed. The report also addressed opportunities and issues specific to the application of natural ventilation to commercial buildings in California including analysis of climate suitability via a new ventilative cooling metric, consideration of ambient air quality, and discussion of relevant codes and standards. It also reviewed current design and analysis processes and tools and described a plan for the development of new design and analysis guidance and tools.

The key recommendation of the earlier report was to develop a software tool to implement the *Loop Equation Design Method* within the existing multi-zone modeling environment of CONTAM [2] to gain the advantages of the existing user interface, airflow element base, and capability to perform detailed analysis after completing the natural ventilation system design. The *Loop Equation Design Method* (presented in detail by Emmerich et al. [1]) is a method for sizing of natural ventilation components that is general and practical and allows direct consideration of stack and wind-driven airflow that is critical in addressing natural ventilation airflow. The tool should assist the designer in performing the needed steps of developing the natural ventilation system design including: establishing the global geometry and topology of zones and interconnecting flow paths, establishing design conditions, setting up and solving the representative loop equations based on the “design” form of the airflow components, and analyzing operation under a variety of conditions.

This report describes the first version of the LoopDA program (for **Loop Design and Analysis** tool), which was developed as a version of CONTAM. The report is organized into three main sections – Loop Equation Design Method (a brief review of the method implemented in LoopDA), the LoopDA Software Tool (a description of the program and how to use it), and Design Example Using LoopDA (an example application of LoopDA to the design of a natural ventilation system for a small commercial building).

2 LOOP EQUATION DESIGN METHOD

The Loop Equation Design Method that is proposed for the Design Development stage of the overall design process of a natural ventilation system is described in detail by Emmerich, Dols, and Axley[1]. (Note: The other design stages – Conceptual Design and Design Performance Evaluation – both precede and follow the Design Development Stage and are also described in [1]. Detailed theory of the method is presented in [3] and [4].). The *Loop Equation Design Method* consists of the following eight steps:

1. Lay out the global geometry and multi-zone topology of the natural ventilation flow loops for each zone of the building.
2. Identify an ambient pressure node and additional pressure nodes at entries and exits of each flow component along the loops.
3. Establish design conditions: wind pressure coefficients for envelope flow components, ambient temperature, wind speed and direction, and interior temperatures; evaluate ambient and interior air densities.
4. Establish first-order design criteria (i.e., a ventilation objective) and apply continuity to determine the objective design airflow rates required for each natural ventilation flow component.
5. Form the forward loop equations for each loop established in step 1 above by systematically accounting for all pressure changes while traversing the loop.
6. Determine the minimum feasible sizes for each of the flow components by evaluating asymptotic limits of the loop equation for the design conditions.
7. Develop and apply a sufficient number of technical or non-technical design rules or constraints to transform the under-determined design problem defined by each loop equation into a determined problem.
8. Develop an appropriate operational strategy to accommodate the regulation of the natural ventilation system for variations in design conditions.

As detailed in the following section, the user will perform some of these steps explicitly (e.g., Step1). Other steps are performed implicitly by LoopDA without user interaction (e.g., Step 5). Still others are accomplished by a combination of explicit and implicit actions (e.g., Step 3).

3 THE LOOPDA SOFTWARE TOOL

LoopDA was developed as a means to perform the eight steps of the *Loop Equation Design Method* presented in the previous section. While it does not fully automate all eight steps, it greatly simplifies and provides a means to manage the entire process.

Specifically, the software accommodates each of the steps as follows:

1. LoopDA provides a SketchPad interface that enables you to draw a schematic representation of the global geometry and multizone topology of the building and to draw the natural ventilation flow loops through the relevant airflow paths of the building.
2. The SketchPad provides the ambient pressure node and keeps track of the pressure nodes associated with each of the airflow paths that you identify on the SketchPad. The direction in which you draw the loops establishes the intended direction of natural ventilation airflow for the purposes of design.
3. LoopDA provides for the establishment of design conditions by allowing you full control in setting ambient conditions of temperature, wind speed and direction. It also enables you to set the design temperatures of all airflow paths and automatically calculates the air densities of each. The program also provides a means to input the wind pressure coefficient of all exterior openings.
4. LoopDA provides a means for you to define the first-order design criteria for each airflow path to be sized, however, it is up to you to select the design criteria and to ensure that continuity is not violated in the event that an opening serves multiple flow loops.
5. Once you have established the geometry, design conditions and criteria and drawn the flow/pressure loops, LoopDA will form the forward loop equations for each loop by traversing the loop in the established direction and accounting for pressure changes due to the pressure/flow relationships of the various flow components, wind and stack effects.
6. LoopDA calculates the minimum feasible sizes of each unsized flow component in a loop by evaluating asymptotic limits of the loop equation for the design conditions.
7. LoopDA provides the ability to export loop information to a spreadsheet template (provided with the program) that displays all the data associated with a given loop, generates asymptotic plots and thus provides a means to view relationships between the flow components of a loop. This aids the application of design constraints, selection of component sizes and documentation of the steps in designing the natural ventilation airflow paths.
8. Having sized the natural ventilation airflow, you can then utilize LoopDA to analyze the building performance under varying conditions. LoopDA implements the established multizone building simulation capabilities of CONTAMW 2.0. You perform analysis to investigate the effects of unintentional air infiltration, non-design weather conditions, and forced-flow elements to simulate hybrid ventilation systems.

3.1 Installing and Running LoopDA

LoopDA runs on Windows 95/98/NT/XP/2000. There are three basic components to LoopDA software system: the main Windows executable program *LoopDA.EXE*, the spreadsheet template *LOOPDATEMPLATE.XLS*, and the analysis or simulation engine *CONTAMX2L.EXE*.

The setup files are contained in the self-extracting archive file "LoopDAz.exe." Simply execute the self-extractor to decompress the setup files. Extract the files to the subdirectory of your choice, or simply select the default location. Once you have extracted the setup files, you can run the setup program, "setup.exe." This will prompt you to perform an automatic installation of the program. Read the instructions to complete the installation.

□ Files Installed

The following table lists the files installed by the setup program. For each file, the directory to which it is installed, the name and a brief description are given. The <program> directory is that selected by you when you install the program. The default is C:\Program Files\LoopDA. The directory is that of the operating system fonts. The default is <windows>/FONTS, where <windows> depends on the operating system you are using, e.g., Windows 2000 <windows> = WINNT and Windows 95/98 <windows> = WINDOWS.

Directory	File Name	Description
<program>	LoopDA.exe	User interface
	Contamx2l.exe	Solver
	cwhelp2.hlp cwhelp2.cnt	CONTAMW help files
	olch2d32.dll roboex32.dll	Charting and help display dynamic link libraries
	LoopDA.doc	LoopDA documentation to be used in conjunction with CONTAMW help files
<program>\samples	*.prj	Sample project files
	*.xls	Spreadsheet files
	walton###.fnt	SketchPad fonts where ## ranges from 01 to 16 for different SketchPad resolutions

□ Uninstalling LoopDA

The LoopDA setup program will also provide you with an uninstall feature. You uninstall LoopDA much as you would a typical Windows program. Access the **Control Panel** from the **Settings** selection of the **Start** menu. Select Add/Remove Programs from the Control Panel. Select LoopDA from the list of installed programs and click the "**Add/Remove...**" button to uninstall LoopDA.

□ Running LoopDA

After you install LoopDA, you can run it by selecting LoopDA from the NIST program group of the Start menu.

3.2 Basic Approach to Design Using LoopDA

This section presents a brief overview of the basic steps to take to implement the Loop Equation Design Method using LoopDA to size the airflow components of a natural ventilation system. Ideally you would perform steps a – d once for a given model of a building and iterate through steps e and f. The details of each of these steps are presented in the following section *Working with LoopDA*. Step g is the process of performing simulations based on your design.

- a. Define ambient design conditions (see Working with Weather and Wind)
Set temperature, wind speed and wind direction
- b. Draw the elevation view of the building (see Working with Walls and Zones)
Draw the walls
Define the zones
- c. Draw ventilation airflow and duct flow paths to be sized (see Drawing Airflow Paths and Drawing Ducts)
- d. Define airflow and duct flow elements (see Working with Inverse Airflow Elements and Working with Inverse Duct Flow Elements)
Select inverse element type
Set design airflow rate Q_{des}
Set design temperature T_{des}
Set wind pressure coefficient $C_p(\theta)$
- e. Draw loops (see Working with Pressure Loops)
View loop data
Export loop data
- f. Import into spreadsheet (see Working with the LoopDA Spreadsheet)
- g. Perform analysis
Set the forward element properties based on design values.
Switch to *analysis mode* and run simulation as with CONTAMW.

3.3 Working with LoopDA

This section serves as a user guide for LoopDA. Using LoopDA is very similar to using CONTAMW, so the information contained in this section is presented as a supplement to the CONTAMW 2.0 User Manual [2] that is available while running LoopDA as an online help system. References to sections of the CONTAMW User Manual / online help will be given in the following sections as {CW: Section} and the areas in which the two programs differ will be presented in detail.

3.3.1 Working with the SketchPad

When working with LoopDA, a major portion of your interaction will be with the SketchPad or drawing region of the interface to develop a schematic representation of your building. The basic use of the SketchPad is very similar to CONTAM, i.e., drawing, selecting and editing building component data. {CW: Working with the SketchPad} The fundamental difference is that LoopDA presents an elevation view of a vertical section of a building, whereas CONTAMW presents plan views of individual levels of a building. In CONTAMW there are level commands and toolbar buttons that provide access to different building levels. These commands are not available in LoopDA.

Because LoopDA is meant to be both a “true” design tool as well as an analysis tool, it has an additional mode of operation that is not in CONTAMW, i.e., the *Design mode*. You size ventilation components in the design mode and therefore an analysis would not be appropriate due to undefined components. The analysis mode is intended to enable the evaluation of a given design once all of the components have been defined or sized. While in the analysis mode, the drawing tools will be deactivated so that you can’t modify your design. You set the mode of operation via the analysis and design toolbar buttons shown below in Figure 1.



Figure 1 – LoopDA toolbar highlighting Design/Analyses mode buttons

3.3.2 Working with Weather and Wind

The weather and wind features are used to establish the design ambient conditions for both design and analysis modes of operation. However, only the Steady State weather data is relevant to the design mode of operation. Set the ambient temperature, wind speed and direction of the Steady State weather data of the Weather and Wind Properties prior to working with your airflow loops as this data is used in forming the pressure loop equations. Note that because LoopDA presents an elevation view, the wind direction should be from either the left or right side of your drawing. This corresponds to either a direction of 0° or 180° respectively, based on the default *relative north* value of -90° (CONTAMW defaults to 0°) as also established in the Weather and Wind Properties. Also, set the reference wind speed data to obtain the desired *wind speed modifier* for your building location {CW: Defining Steady State Weather and Wind}

The CONTAMW User Manual contains a detailed presentation of how weather and wind are handled by CONTAMW and LoopDA in the analysis mode. {CW: Working with Weather and Wind} As presented in that section, both steady state and transient weather data can be implemented depending on the type of simulation you are performing.

3.3.3 Working with Walls and Zones

The mechanics of drawing walls to form zones are exactly the same as in CONTAMW. The main difference between LoopDA and CONTAMW is that you are drawing elevation views of a building

as opposed to plan views. Each drawing that you create should represent a vertical section of the building in question. To represent multiple sections, you could either draw them individually on a single SketchPad, or you can create individual LoopDA project files for each building section. {CW: Drawing Walls, Ducts and Controls; CW: Working with Walls}

Walls must be drawn so that fully bounded regions are created that make up the *zones* of your building representation. The properties of each zone must then be defined by a zone icon as typical for building components. {CW: Working with Zones} The zone properties are not needed in the design process, but are required during the analysis phase.

3.3.4 Working with Airflow Paths

In LoopDA, airflow paths are the openings between zones, including the ambient, that form direct connections between the zones (as opposed to ducted connections discussed below). In the design mode, you first lay out (draw) the location of the natural ventilation airflow paths that will make up the ventilation flow loops and then define their design properties.

3.3.4.1 Drawing Airflow Paths

You draw airflow paths in LoopDA exactly as done in CONTAMW. However, in LoopDA, you can only place airflow paths directly on walls. {CW: Creating Airflow Paths}

3.3.4.2 Defining Airflow Paths

Once a flow path is drawn you must define its design properties in order to use the path in a ventilation airflow loop. The following items are relevant to the *design mode* of operation, i.e., to form *Loop Design Equations*.

Airflow Element – *Airflow elements* describe the mathematical relationship between the flow through an airflow path and the pressure drop across the path. You must select an airflow element type prior to setting the other parameters. As presented in the following subsection, the design mode is only concerned with *Inverse Airflow Element* types. LoopDA currently supports only two types of inverse airflow elements, but all types of CONTAMW airflow elements are supported in the *analysis mode*. You should create an airflow element for each flow path you want to design in order to maintain a unique set of parameters for each path.

Elevation – Set the elevation of each airflow path relative to the reference height of zero for the bottom of the building. This value will be used in calculating stack pressures in both the design and analysis modes.

Wind Pressure – Set the wind pressure to be variable and define a wind pressure coefficient profile. You can simply set this to be a constant profile or to vary according to the angle of incidence of the wind on the wall or flow path. {CW: Airflow Path – Wind Properties} Care should be taken when defining flow paths on horizontal walls, as they will default to have azimuth angles that might not make sense. Be sure to set the reference wind speed modifier to the desired value either individually for each flow path or globally via the Weather data that defaults to provide a modifier of 1.0.

Detailed information on the analysis parameters are provided in {CW: Working with Airflow Paths}, and details of working with the Inverse Airflow Element data are provided below.

3.3.5 Working with Inverse Airflow Elements

Basically, an *inverse airflow element* is one that can be sized using the loop equation design method. In CONTAM, airflow component equations are formulated in the so-called “forward” form while the loop method uses these same equations in “inverse form” – a form relating the pressure drop across components to the volumetric (or mass) flow rate and characteristic design parameters (CDP), e.g., an area for an orifice element. A detailed discussion of inverse airflow elements is presented in Axley [3] and [4].

This version of LoopDA supports two types of inverse airflow elements: orifice and general power law. The mathematical relationships for each are presented here in forward and inverse form.

□ Orifice Element

Forward form:
$$\dot{V} = C_d A_{orfc} \sqrt{2\Delta p / \rho}$$

Inverse form:
$$\Delta p = \frac{\rho \dot{V}^2}{2C_d^2 A_{orfc}^2}$$

Characteristic Design Parameter: A_{orfc}

Corresponding Analysis Parameter: *Cross sectional area*

□ General Power Law Element

Note: This element can be used to represent a range of flow paths, including a self-regulating vent when a relatively large value of the exponent n is specified [2].

Forward form:
$$\dot{V} = C (\Delta p)^n$$

Inverse form:
$$\Delta p = \left(\frac{\dot{V}}{C} \right)^{\frac{1}{n}}$$

Characteristic Design Parameter: C

Corresponding Analysis Parameter: *Flow coefficient (C)*

3.3.5.1 Creating Inverse Airflow Elements

To create an inverse airflow element you select the “New Element” button on the Flow Element page of the Airflow Paths Property Sheet that is displayed when defining an airflow path. This will display a list of all available types of *forward airflow elements*. Select either the general *power law element*, represented in the list as $Q = C(dP)^n$, or the *orifice element* from the list of elements on the Airflow Element Models dialog box. This will reveal the Airflow Element Properties sheet that contains two pages of parameters: one that contains the analysis parameters specific to the type of model selected and one containing the design parameters for the inverse element.

3.3.5.2 Defining Inverse Airflow Elements

Figure 2 shows the Airflow Element Properties sheet for an orifice element and the design parameters associated with the element. The parameters on the Design page are those used in formulating the pressure loop equations along with the previously mentioned airflow path properties.

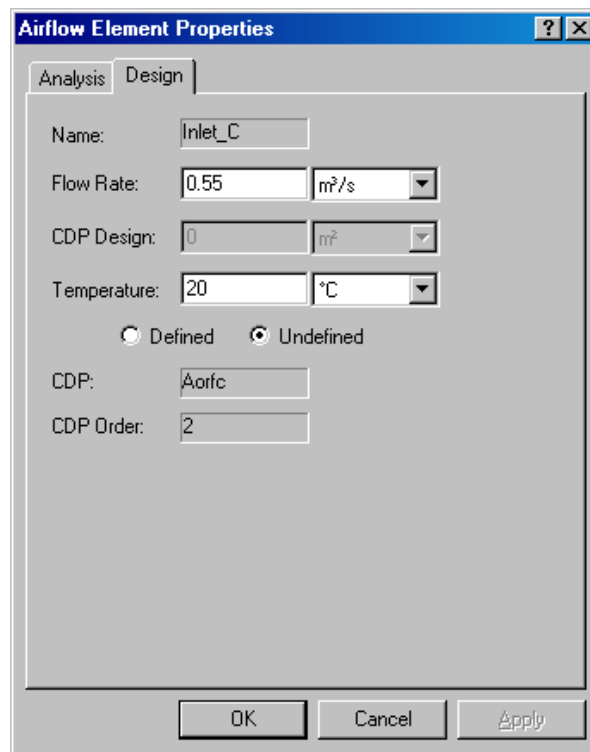


Figure 2 – Airflow Element Properties sheet displaying design data for an inverse orifice element

For each of these inverse elements the design page displays information that is specific to the element for which the properties are being displayed. The following is a description of each of the properties displayed.

- ❑ **Name:** This is the airflow element name you provide for this element. This name is used for both the forward and inverse flow element.
- ❑ **Flow Rate:** Specify the design flow rate for this element. It is your responsibility to ensure that design flows do not violate continuity when multiple loops pass through common flow paths, as is the case for Loops 2 and 3 in Figure 9 of the example presented later.
- ❑ **CDP Design:** Once you have selected a value for the *CDP* (characteristic design parameter), enter it here and select *Defined* as described below. The type of parameter this value represents will depend on the type of inverse element you are sizing.
- ❑ **Temperature:** Set the design air temperature for this element.
- ❑ **Defined/Undefined:** Select *Undefined* when the element has not yet been sized. As you select sizes for elements, you set their *CDP Design* values and set them to be *Defined*.
- ❑ **CDP:** This is the name given by LoopDA for this particular element. This will be either A_{orfc} or C_e corresponding to the *orifice* and *power law* elements respectively. When you view and export loop data, a distinct area or diameter identifier will be provided for the element. This identifier will include the path number assigned by LoopDA.
- ❑ **CDP Order:** This is the order of the exponent of the design parameter as it would appear in the loop design equation as detailed by Axley [3] and [4]. This will be either 2.0 or 1/n corresponding to an area (orifice) or flow exponent (general power law) respectively.

3.3.6 Working with Ducts

You can use LoopDA to size duct segments and inlet and outlet terminals that represent stacks or connections between zones. In the design mode, you first draw the individual duct segments then define their design properties. LoopDA implements the *Darcy-Colebrook* duct flow element. This element provides for the sizing of both *duct flow segments* based on a friction factor and *fittings* (inlets and outlets) based on a loss coefficient.

3.3.6.1 Drawing Ducts

You draw ducts in LoopDA exactly as done in CONTAMW. However, in LoopDA, you are working in the elevation view. {CW: Working with Ducts} You should draw duct segments for each inlet, airflow segment and outlet of a duct as shown in the figure below. This will provide a separate term in the loop equation for each component of the duct system. The details of defining duct segments and terminals will be presented in the following sections.

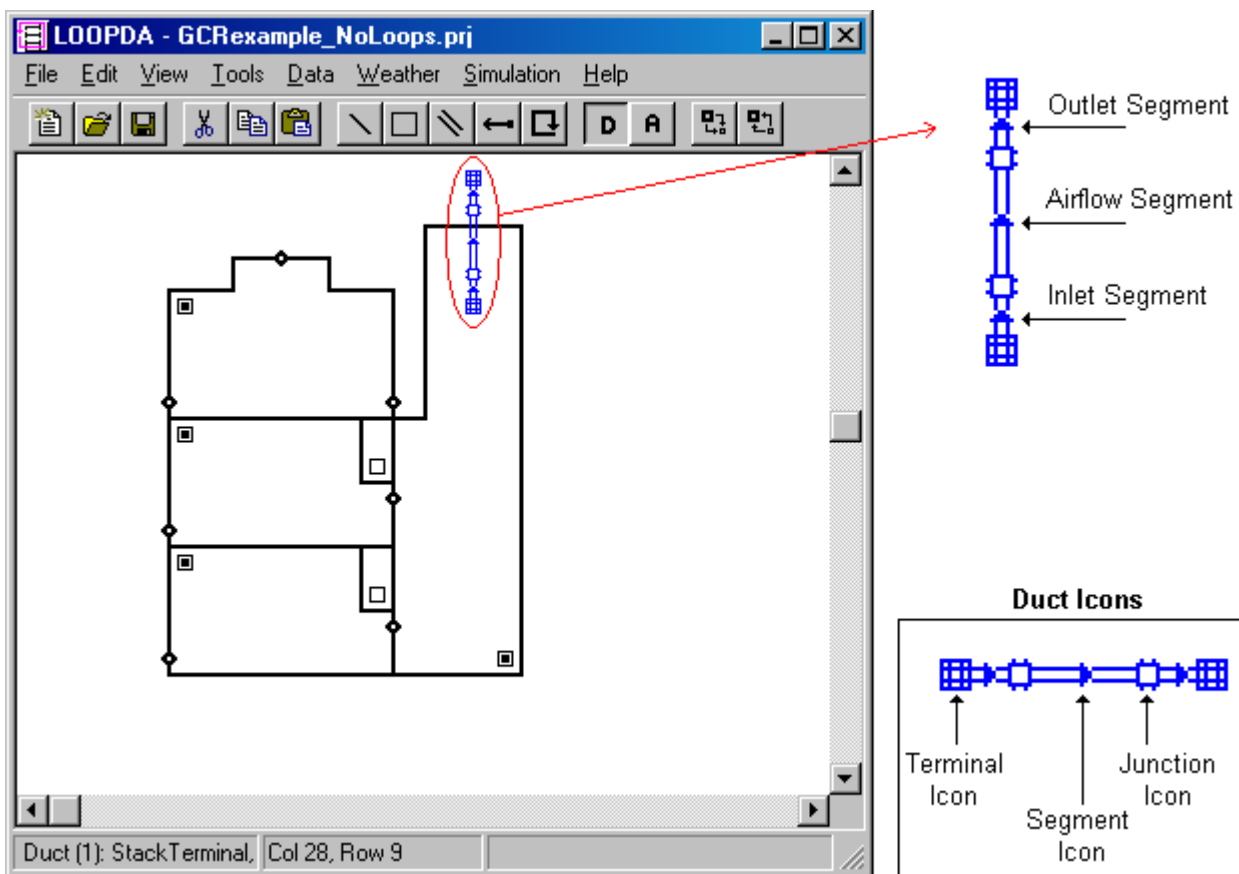


Figure 3 – Detail for drawing ducts for loop analysis

3.3.6.2 Defining Ducts

Once a duct is drawn you must define its design properties in order to use it in a ventilation airflow loop. The following items are relevant to the *design mode* of operation, i.e., to form *Loop Design Equations*.

Duct Flow Element – *Duct flow elements* describe the mathematical relationship between the flow through a duct segment and the pressure drop across the path. You must select a duct flow element type prior to setting the other parameters. As presented in the following subsection, the design mode is only concerned with *Inverse Duct Flow Element* types. LoopDA currently supports only one type of inverse duct flow element, but all types of CONTAMW duct flow elements are supported in the *analysis mode*.

Select whether you want to create an *Airflow Segment* or *Terminal/Fitting* (use this for creating *inlets* and *outlets* that you want to size based on a loss coefficient). This will enable/disable and zero-out various input parameters for the duct to help insure that you define only those that are relevant to the type of segment as described below.

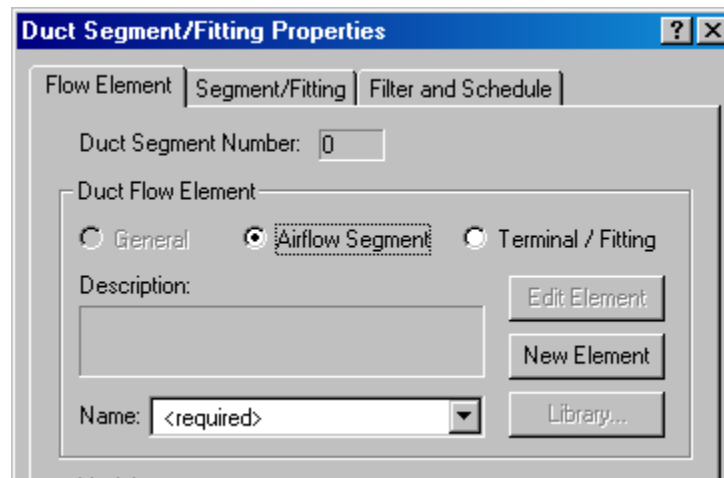


Figure 4 – Duct segment/fittings properties sheet

Segment Length – If you are defining a segment icon to be a duct segment (as opposed to a terminal), provide a value for the *Duct segment length* and make sure the *Sum of loss coefficients* is set to zero.

Friction Factor – If you are defining a segment icon to be an *airflow segment*, provide a value for the *Friction factor*. You can use the friction factor calculator provided on the Duct Airflow Element Properties input dialog box to help determine this value and the *Roughness* value for analysis.

Segment Sum of Loss Coefficients – If you are defining a segment icon to be a duct *Terminal/Fitting* (inlet or outlet), then provide a value for the *Sum of loss coefficients* and make sure the *Duct segment length* is set to zero.

Elevation – Set the *elevation* of each *duct junction* and *terminal icon* relative to the reference height of zero for the bottom of the building. This value will be used in calculating stack pressures in both the design and analysis modes. Note that the difference in elevations of adjacent junctions is not necessarily the same as the length of the segment between them.

Wind Pressure – See previous Defining Airflow Paths section.

3.3.6.3 Working with Inverse Duct Flow Elements

Inverse duct flow elements are similar in nature to airflow elements. This version of LoopDA supports only the Darcy-Colebrook type of inverse duct flow element. However, this element can be used to size either a *Duct component (Airflow segment)* or *Duct fitting component (Fitting/Terminal)* as described by Axley [2]. The forward form shown below is that implemented in CONTAM. This form can be split into two terms: one containing the loss due to the friction factor f (and the duct dimensions) and one containing the losses due to fittings ΣC_d .

□ Darcy-Colebrook Element

Forward form:
$$\dot{V} = \sqrt{\frac{2A^2 \Delta p}{\rho(fL/D_h + \Sigma C_l)}}$$

Inverse forms:

Duct component
$$\Delta p = \frac{\rho \dot{V}^2}{2A^2} \frac{fL}{D_h} = \frac{\rho \dot{V}^2}{2D_e^5} fL$$

Characteristic Design Parameter: Equivalent duct diameter D_e which simplifies to the actual diameter D for circular ducts (See Chapter 34 of [5] for a discussion of hydraulic, actual and equivalent duct diameters.)

Corresponding Analysis Parameter: *Duct shape and dimensions*

Relevant Parameters: Set segment *Sum of loss coefficients* C_l to 0.0. Design value for friction factor f and *Duct Shape*.

Duct fitting component
$$\Delta p = \frac{\rho \dot{V}^2}{2A^2} \Sigma C_l$$

Characteristic Design Parameter: Opening area A

Corresponding Analysis Parameter: *Duct shape and dimensions*

Relevant Analysis Parameter: Set *Duct segment length* L to 0.0
Note: *friction factor* and *duct shape and dimensions* are not relevant to fittings

3.3.6.4 Creating Inverse Duct Flow Elements

To create an inverse duct flow element you select the “New Element” button on the Flow Element page of the Duct Segment/Fittings Properties sheet that is displayed when defining a duct flow path. This will reveal the Duct Airflow Element Properties sheet that contains three pages of parameters: one that contains the analysis parameters specific to the Darcy-Colebrook duct model, one containing *Shape, Size and Leakage* data and one containing the *Design* parameters for the inverse element.

3.3.6.5 Defining Inverse Duct Flow Elements

Figure 5 shows the Duct Airflow Element Properties sheet for a Darcy-Colebrook element and the design parameters associated with the element. The parameters on the *Design* page are those used in formulating the pressure loop equations along with the previously mentioned duct flow path properties.

The screenshot shows a software dialog box titled "Duct Airflow Element Properties" with three tabs: "Darcy-Colebrook Model", "Shape, Size and Leakage", and "Design". The "Design" tab is active. The dialog contains several input fields and a section for friction factor estimation.

Field	Value	Unit
Name	StackInlet	
Segment Type	Fitting/Terminal	
Flow Rate	2.2	m³/s
CDP Design	0	m²
Temperature	26	°C
Friction factor	N/A	
Defined/Undefined	<input type="radio"/> Defined <input checked="" type="radio"/> Undefined	
CDP	A	
CDP Order	2.0	

Estimate Friction Factor
Friction factor is a function of Re and Roughness. Use this to estimate a design friction factor and to compare w/ analysis.

Field	Value	Unit
Roughness	N/A	m
Velocity	N/A	m/s
Dh	N/A	m
Re	N/A	
Friction factor	N/A	

Buttons: OK, Cancel, Apply

Figure 5 – Duct Airflow Element Properties sheet displaying design data for a Darcy-Colebrook element (Fitting/Terminal)

For each of these inverse elements the design page displays information that is specific to the element for which the properties are being displayed. The following is a description of each of the properties displayed.

The Name, Flow Rate, Temperature and Defined/Undefined items are the same as described in the case of inverse airflow elements.

- ❑ **Segment Type:** This indicated whether the duct segment icon represents an Airflow segment or a Fitting/Terminal segment as selected when defining the Duct Segment/Fitting Properties (see Figure 4).
- ❑ **CDP Design:** Once you have selected a value for the *CDP* (characteristic design parameter), enter it here and set the element to be “defined.” The type of parameter this value represents will depend on the type of inverse element you are sizing. This will be either an *equivalent duct diameter* D_e or opening area A depending on whether you are sizing a duct or terminal, respectively. Further, D_e is the actual diameter when dealing with circular ducts as described in Chapter 34 of the ASHRAE Fundamentals [5].
- ❑ **Friction Factor:** This value is only required for *airflow segments* and is ignored for *fittings/terminals*. It is dependant on the roughness and Reynolds number. Therefore, it is indeterminable at design time, because the flow, and hence the velocity, in the duct is not known.

You can use the right side of the page to estimate a design friction factor. Details on friction losses are presented in Chapter 34 of the ASHRAE Fundamentals [5].

- **CDP:** This is the name given by LoopDA for this particular element. This will display “A” or “De” to indicate either area or diameter for *fitting/terminal* segment or *airflow segment* respectively. However, when you view and export loop data, a distinct area or diameter identifier will be provided for the element. This identifier will include the duct segment number assigned by LoopDA.
- **CDP Order:** This is the order of the exponent of the design parameter as it would appear in the loop design equation as detailed by Axley [3] and [4]. This will be either 2.0 or 5.0 corresponding to an area (*fitting/terminal*) or diameter (*airflow segment*) respectively.

3.3.7 Working with Pressure Loops

Once you have defined the paths and ducts that you want to size, you can now form pressure loops that define the desired airflow paths of ventilation air through the building. The basic method consists of drawing loops by connecting design flow paths and ducts on the SketchPad in the direction that air should flow through them; selecting the loop to generate a loop equation; reviewing loop properties within LoopDA; exporting loop data to a spreadsheet template to view loop equation details, review asymptotic plots and apply design constraints to select component sizes. Once you decide on the size of an element in a loop, you return to LoopDA and set that element’s CDP and regenerate the loop equation so that the defined element is “moved to the right hand side” of the loop equation. Continue this process until all elements in a loop are sized and for each loop under consideration.

3.3.7.1 Drawing Loops

Drawing loops is very similar to drawing walls with the wall drawing tool {CW: Drawing Walls}. Select the loop drawing tool from the toolbar as shown highlighted in Figure 6.



Figure 6 – LoopDA toolbar highlighting the Loop Drawing Tool button

The following rules apply when drawing loops:

- You must begin drawing loops in the ambient zone.
- Draw loops in the direction you want air to flow through the building.
- Each loop must end where it began (LoopDA will automatically complete the loop when you reach the beginning cell on the SketchPad).
- Each loop must contain exactly two flow paths that are connected to the ambient, i.e., an inlet into the building and an outlet from the building.
- Loops are allowed to cross over and share common sections with the exception of the loop direction/selection arrow.
- Loops may not cross over themselves.

3.3.7.2 Selecting Loops

To select a loop once it is drawn click on its direction arrow. This will highlight the loop in orange as shown later in the description of the pressure loops of the design example (see Figure 9).

3.3.7.3 Deleting Loops and Loop Elements

To delete a loop, select it to then click the Delete key on the keyboard or select Edit→Delete from the menu. You should always delete loops that pass through any airflow or duct flow paths before you move or delete the paths or ducts through which a loop passes.

3.3.7.4 Viewing and Exporting Loop Data

To access loop properties either select the loop then press the Enter key on the keyboard or double-click on the loop selection arrow. This will display the Pressure Loop Properties dialog box (see Figure 11 presented later in the Pressure Loops section of the design example). This dialog box displays the following information:

- **Loop Number:** This is an identification number assigned by LoopDA.
- **Name:** You can enter an optional name for this loop to help you identify it when you export it to a spreadsheet.
- **Description:** You can enter an optional detailed description for this loop to help you further identify it when you export it to a spreadsheet. This can be very useful as you progress through the iterative stage of sizing elements in that same loop.
- **Number of Loop Nodes:** This is the number of airflow paths, duct junctions, terminals and segments through which the loop passes.
- **Number of Equation Terms:** This is the number of terms that would appear on the left hand side of the pressure loop equation. There will be an equation term for each airflow path and duct segment through which the loop passes, i.e., the sizable components, whether defined or undefined.
- **Driving Pressures:** These are the pressure differences induced by the wind and buoyancy-driven airflows for the selected loop. In terms of the loop equation, these are the values that appear on the right-hand-side of the equation.

Wind: This is the sum of the wind pressures acting on the two external openings of the loop in consideration.

$$\Delta P_w = \Delta C_p \frac{\rho_o C_h U_{met}^2}{2}$$

ΔC_p is the algebraic sum of pressure coefficients. It is summed positively when traversing the loop from the exterior to a wall surface and negatively otherwise.

ρ_o is the density of the outdoor air calculated by LoopDA based on the ambient temperature as entered in LoopDA (and CONTAMW) under Weather and Wind Parameters.

U_{met} is the design wind speed at the meteorological station as entered in LoopDA (and CONTAMW) under Weather and Wind Parameters.

C_h is the wind speed modifier determined based on terrain and elevation effects in LoopDA (and CONTAMW) under Weather and Wind Parameters.

Stack: This is the sum of the buoyancy-induced stack pressure differences determined by traversing the loop systematically in the order of airflow accounting for differences in density and elevation along the way.

$$\Delta P_s = g \sum \rho_{ij} \Delta z_{ij}$$

g is the acceleration of gravity (9.81 m/s²).

ρ_{ij} is the density of air within the flow element based on the design air temperature of the inverse element.

Δz_{ij} is the difference in elevation between two nodes in the loop. It is positive for drops and negative for rises in elevation along the loop.

Total Pressure Drop (RHS): This is the total pressure drop available to drive airflow through the undefined airflow components. This accounts for any defined Flow Element Terms within the loop in question and is the value that would appear on the right-hand-side (RHS) of the loop equation.

$$\Delta P_{Total} = \Delta P_s + \Delta P_w - \sum \Delta P_{defined}$$

- **Flow Element Terms:** This is a detailed accounting of each term that would appear on the left-hand-side of the loop equation. It includes the *Type* of component (path or duct), the component number # (as assigned by LoopDA), the *Name* of the characteristic design parameter including the appended component number, the *Order* of the exponent of the CDP as it would appear in the loop equation, the value of the element-specific *Numerator* that would be associated with this component in the loop equation, the *Asymptote* or minimum value of the CDP that would provide the total pressure drop equivalent to the RHS value above, whether or not the item is *Defined* or has been sized and should be accounted for on the RHS of the loop equation, and the *Value* of the CDP if it has been defined.

The Element Term that is highlighted in this list will be that against which all others will be plotted when the asymptotic plots are generated by the spreadsheet once the loop data is imported into the LoopDA spreadsheet template. You can select the component against which you would like all others to be plotted. By default the CDP with the highest order is highlighted unless it is already defined. If all undefined elements have the same order, then the first element in the list is highlighted.

- **Export Loop Button:** Click this button to export loop data. You will be prompted to give the file a name (having a default extension of .txt). This will create a tab-delimited ASCII file that can be easily imported into the LoopDA spreadsheet template. Make note of the name and location of the file you save, so you can locate it for importing into a spreadsheet program.

3.3.8 Working with the LoopDA Spreadsheet

This version of LoopDA takes advantage of the powerful features of spreadsheet software by exporting loop data in a format compatible with typical spreadsheet programs. A spreadsheet template is provided with the software that simplifies the presentation of the loop equation data generated by LoopDA. Along with the LoopDA project file, the spreadsheet also serves as a means of documenting the steps you go through in performing your design analysis.

The sections immediately following provide the mechanics of using the LoopDA spreadsheet, whereas the practical use of the spreadsheet in the Pressure Loop Sizing Method is presented further along in the Design Example.

3.3.8.1 *LoopDA Spreadsheet Template*

The LoopDA spreadsheet template is a simple spreadsheet that contains headings for the loop data, a section that calculates plot ranges for the CDPs, and a chart for each set of loop data you import that automatically plots the imported data.

The exported data provide much more detailed information than is presented in the *Pressure Loop Properties* dialog box. The data is subdivided into the following sections:

- File Information
- Loop Information
- Outdoors
- Wind Pressures
- Stack Pressures
- Loop Flow Elements
- CDP Asymptotic Values
- Chart Data

3.3.8.2 *Saving Loop Spreadsheets*

Before you begin working with the LoopDA spreadsheet template, you should save it under a new name specific to your current project. It's up to you as to how you manage your loop spreadsheets. One way is to maintain a separate spreadsheet for each loop that contains the various stages of undefined elements. The template is preset with four sets of data pages and asymptotic plot pages. You can easily increase the number of pages by simply copying the existing ones.

3.3.8.3 *Importing Loop Data*

To import a LoopDA-generated loop file, open the file using your spreadsheet software and parse it as a tab-delimited file. Then simply select the top left cell of the desired sheet in the template (typically A1) and paste the data (values only using the Paste Special... command for example).

3.3.8.4 *Plotting Loop Data*

Data will be plotted automatically for up to five elements (four terms vs. one). You can expand this by simply copying the cells located in the bottom of column E to the column(s) on the right of E.

3.3.9 Performing Analysis

Be sure to set the forward element parameters based on your design values.

4 DESIGN EXAMPLE USING LOOPDA

4.1 Sample Building

The use of LoopDA to design a natural ventilation system is demonstrated using an example from Axley [3]. The sample building is based conceptually on the Inland Revenue Building in England (see [6] for more detail on this building). It is worthwhile to note that by using this sample building the Conceptual Building phase mentioned above is already completed – allowing us to focus on the Design Development phase.

Figure 7 shows an elevation section view of this building model. As seen in the figure, the building is three stories tall with the 1st and 2nd floors being ventilated by air flowing in through inlet *orifices* *a* and *c* and out through a common exhaust stack represented by *zone s* and *opening h*. The 3rd floor is ventilated by air flowing in through two *self-regulating inlet vents* *e* and *f* (see [3] for a detailed description of these vents) and out through another exhaust stack represented by *opening g*. Each zone of the building has a volume of 800 m³.

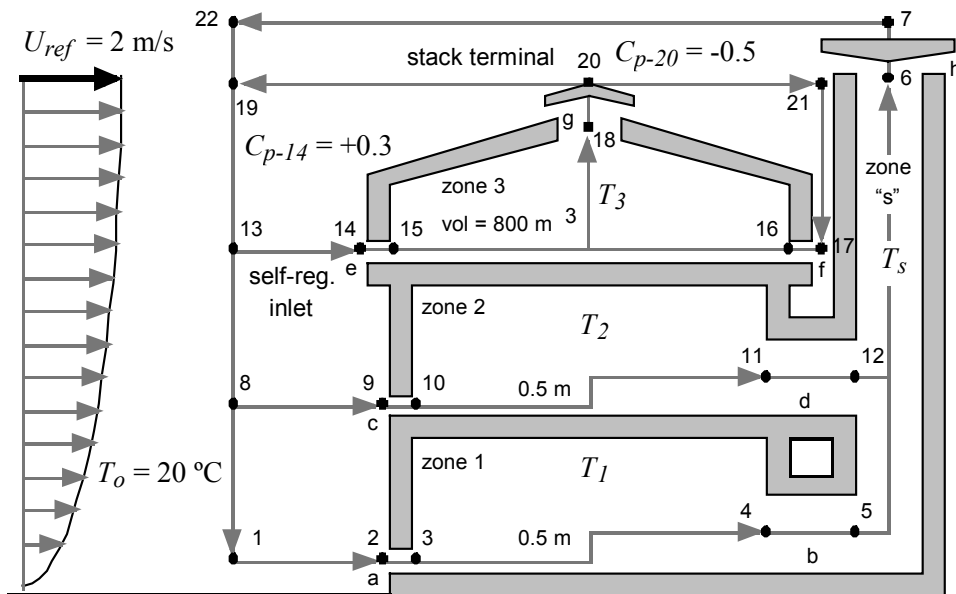


Figure 7 – Global geometry, topology, and pressure nodes for the ventilation flow loops of a building model based on the Inland Revenue Building, England (repeated from Figure 3.16 of Axley 2001)

4.2 Design Conditions and Criteria

In addition to the global geometry presented in Figure 7, the designer must select indoor temperatures, outdoor temperature, wind speed, wind pressure coefficients, and ventilation flow rates to perform the design analysis. It is not obvious what values to select for many of these parameters. For example, it may not be sensible to select extremes (e.g., very low wind speed) for the design ambient conditions. Such extremes may rarely occur or may prove too severe a challenge for a pure natural ventilation system. For many U.S. climates, it may be necessary to either tolerate limited periods during which indoor environmental conditions will be outside design conditions considered typical for conventional, mechanically conditioned buildings or to provide some supplemental mechanical systems (i.e., a hybrid ventilation system) for such periods. That said, the procedure followed below provides a realistic example problem only and is not being proposed as

formal guidance for determining design conditions for natural ventilation systems. Emmerich, Dols, and Axley [1] described a simple method to evaluate the suitability of a given climate to cool a commercial building with natural ventilation and went on to apply that method to ten California locations. That analysis indicated that the coastal climates of California are well suited to natural ventilation with respect to climatic considerations. Therefore, the building described above will be situated in San Francisco for the purposes of this sample application of LoopDA. Per the earlier climate suitability analysis, a natural ventilation system could potentially cool a commercial building with combined solar and internal heat gains of 10 W/m^2 to 80 W/m^2 greater than 90 % of the hours of the year with a supplemental night cooling system expected to be effective for any days that would be overheated based on direct ventilative cooling alone. Assuming a heat gain rate of 20 W/m^2 (a low but achievable design target), the required average ventilation rate is 2.2 h^{-1} with a standard deviation of 2.6 h^{-1} . Therefore, a design ventilation rate of 5 h^{-1} (or about one standard deviation above the average) is a reasonable design objective for summer cooling. The coincident design indoor temperature for this summer condition may be selected as $26 \text{ }^\circ\text{C}$ (based on the high end of ASHRAE's summer thermal comfort zone [5]).

Figure 8 shows the hourly outdoor temperatures and coincident wind speeds for the San Francisco TMY2 weather file [7]. From Figure 8, it appears conservative to choose an outdoor temperature of $20 \text{ }^\circ\text{C}$ with a wind speed of 2 m/s for the design conditions as hours with both higher temperatures and lower wind speeds are rare as shown by the dashed box.

Although it is typical to use a wind pressure profile that is dependent on wind direction (and possibly relative location of an opening on a wall), a single design value will be chosen for this example assuming the building will be oriented to take advantage of prevailing wind direction. Per Figure 16.7 of the ASHRAE Handbook of Fundamentals [5], a surface average wind pressure coefficient of 0.3 will be selected for the ventilation openings in the walls. Per Figure 16.9 of the ASHRAE Handbook of Fundamentals [5], a single value of -0.5 will be used for the wind pressure coefficient on the exhaust stacks.

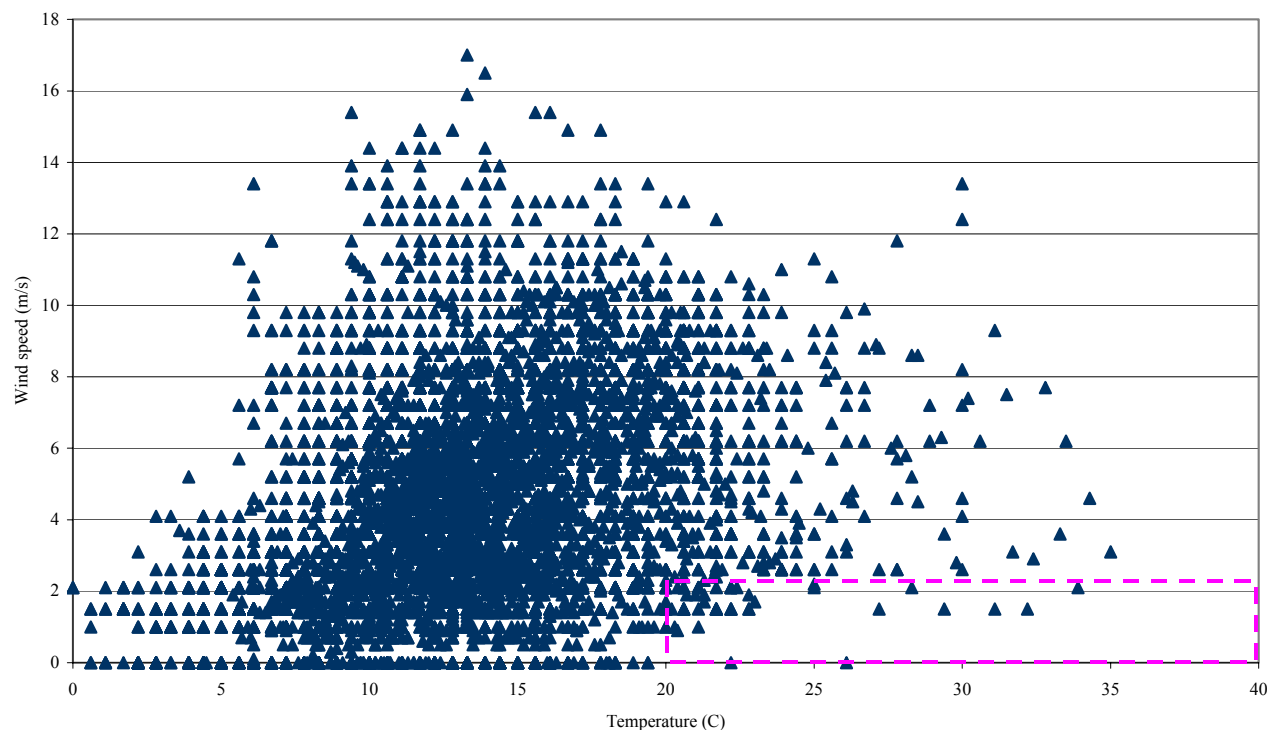


Figure 8 – Wind speeds vs. outdoor temperatures for San Francisco TMY2 weather file

4.3 Pressure Loops

With the building geometry and design conditions established, one may use LoopDA to form the loop equations and size the various natural ventilation system components. Figure 9 shows the LoopDA Sketchpad representation of the building elevation with the four pressure loops that must be analyzed. Loops 1 and 4 are equivalent loops following nodes 13-14-15-18-20-19-13 and nodes 21-17-16-18-20-21 serving *zone 3* (per Figure 7). Loop 2 follows nodes 8-9-10-11-12-6-7-22-8 serving *zone 2* and Loop 3 follows nodes 1-2-3-4-5-6-7-22-1 serving *zone 1*.

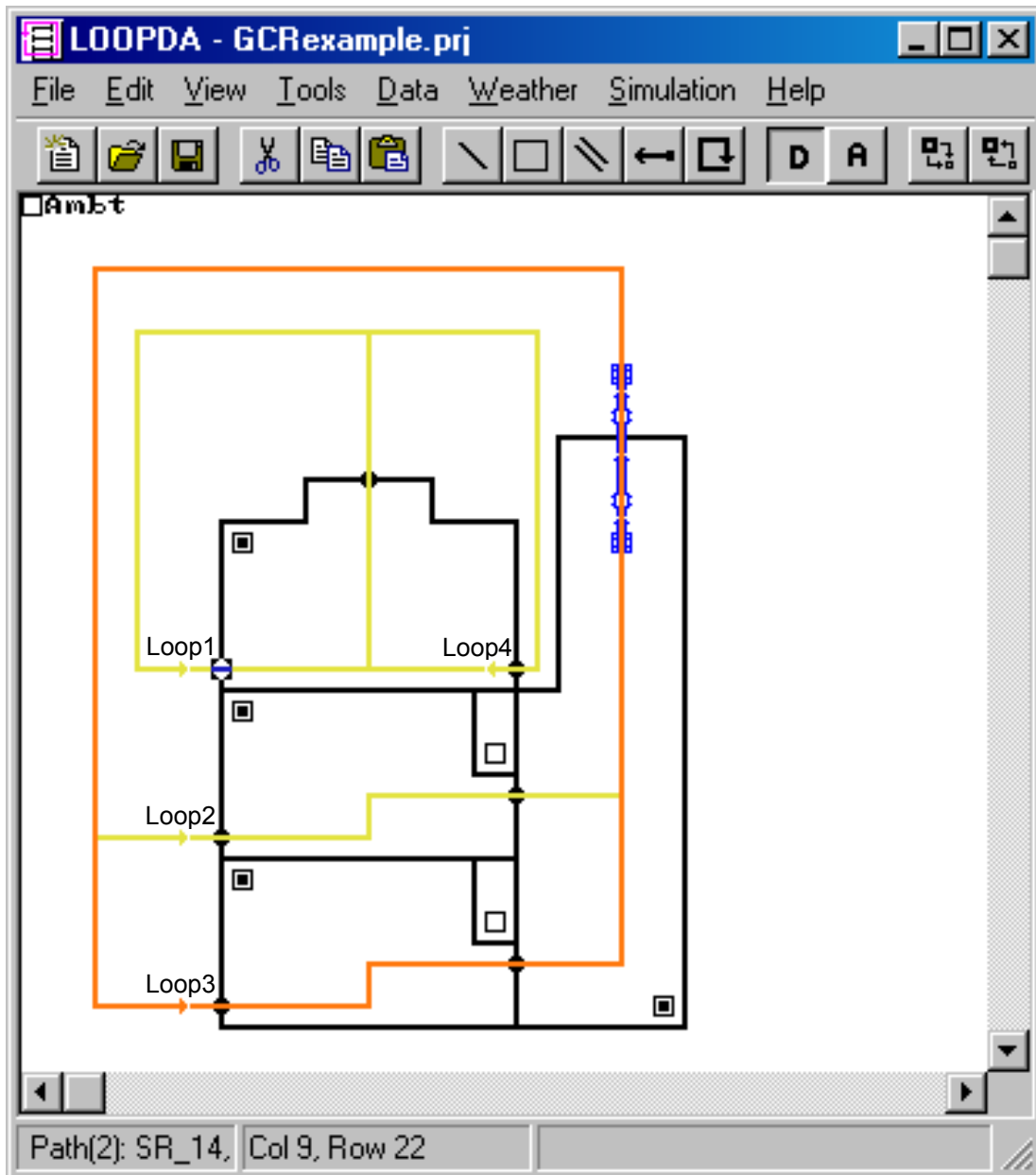


Figure 9 – LoopDA Sketchpad representation of natural ventilation design sample problem

4.3.1 Loops 1 & 4

Loops 1 and 4 are equivalent loops each providing $0.55 \text{ m}^3/\text{s}$ (half of the design 5 h^{-1}) to *zone 3* via self-regulating inlet vents. Both loops exhaust through the *stack terminal g* on Figure 7 for a total design flow of $1.1 \text{ m}^3/\text{s}$ through the stack terminal. The self-regulating inlet vents are modeled in LoopDA as power law flow elements with an exponent of 0.1 (see Axley 2001 for more information) and an undetermined characteristic design parameter (CDP) C_e (see Figure 10). The stack terminal is modeled as an orifice with the area $A_{orfc,g}$ (referred to as A_{orfc1} by LoopDA) as the CDP. The complete pressure loop properties from LoopDA are shown in Figure 11.

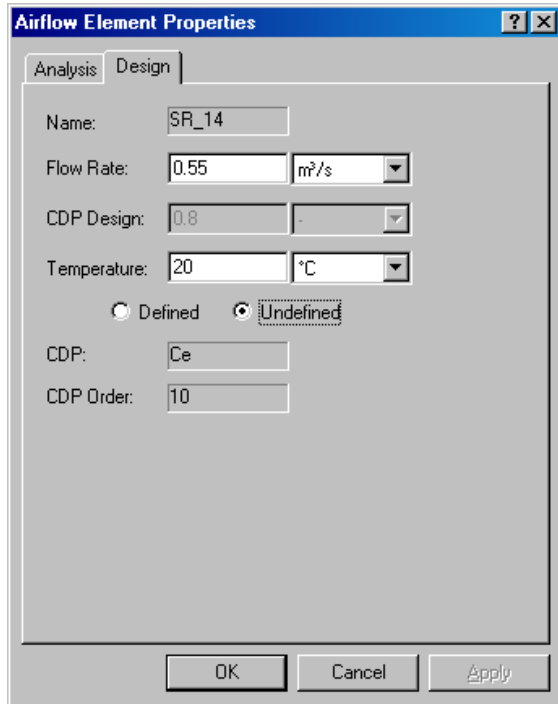


Figure 10 – Airflow element design window for the self-regulating inlet vent of Loop 1

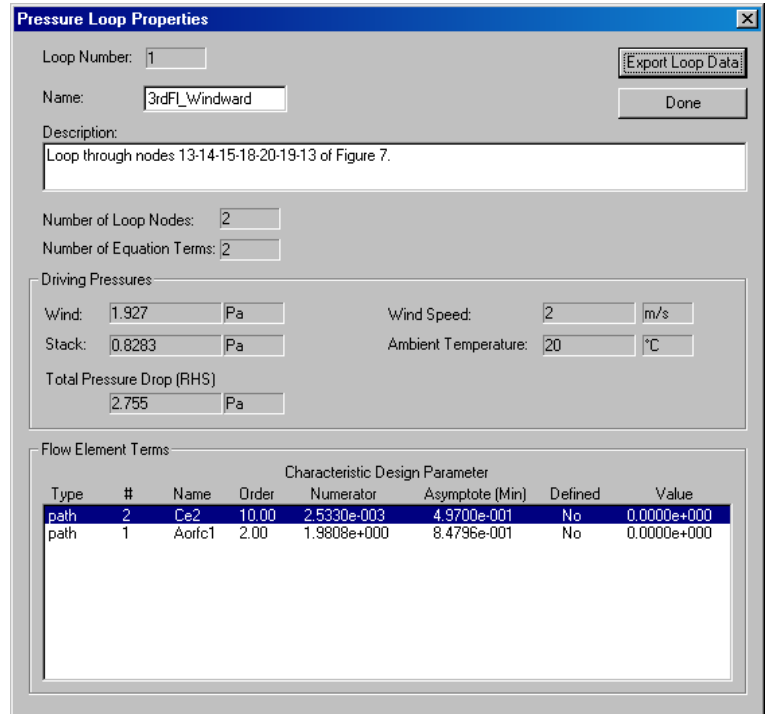


Figure 11 – Pressure loop properties window for Loop 1

After entering the information for Loop 1, the loop data are exported to a tab-delimited file that is pasted into the LoopDA spreadsheet template (click the icon below to view the Loop 1 information as it appears after being pasted into the LoopDA template).



Since Loop 1 has only two elements with undetermined CDPs, the LoopDA template plot is simple and shows the sizing relationship between C_e and $A_{orf,c,g}$ (see Figure 12). From Figure 12, the CDP for either element may be chosen (based on other considerations such as available component sizes from catalog data) and the minimum required size for the other CDP is fixed. For this example, selecting a value of 0.8 for C_e dictates a minimum orifice area of 0.85 m^2 which might be rounded up to 1.0 m^2 based on availability.

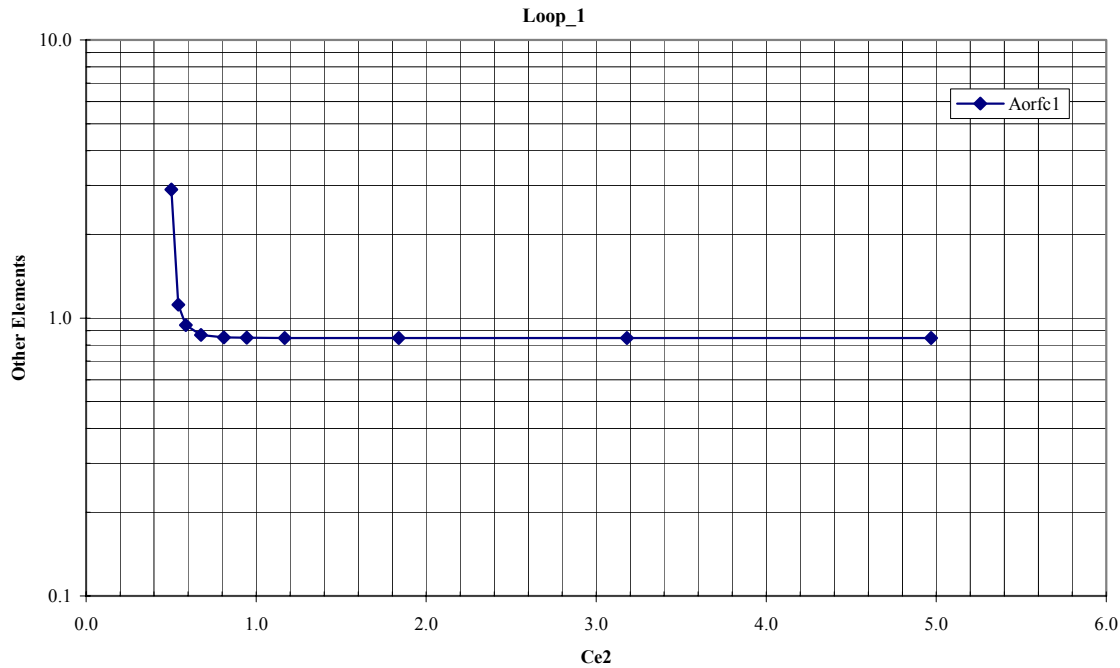


Figure 12 – Asymptotic relationship between CDP of self-regulating inlet vent C_e ($Ce2$) and CDP of stack terminal $A_{orf,c,g}$ ($Aorf1$) for Loop 1

4.3.2 Loop 2

Loop 2 supplies $1.1 \text{ m}^3/\text{s}$ (i.e., 5 h^{-1}) to zone 2 via inlet c on Figure 7. The flow exhausts through outlet d into the stack zone s and out the stack terminal h on Figure 7. Note that the stack must also exhaust the ventilation flow from zone 1 for a total design flow of $2.2 \text{ m}^3/\text{s}$ through the stack. The inlet and outlet vents are modeled in LoopDA as orifice flow elements with $A_{orf,c,c}$ ($Aorf5$) and $A_{orf,d}$ ($Aorf4$) as the undetermined CDPs. The stack is modeled using a Darcy-Colebrook duct model with an orifice as the inlet (the CDP is the area $A3$), an orifice as the outlet (the CDP is $A1$), and a 1m long round duct segment (the CDP is the duct diameter $D3$). The complete pressure loop properties from LoopDA are shown in Figure 13. Note that, if desired, the user must impose the condition that the stack orifice areas be based on the duct diameter during the sizing process as LoopDA treats them as independent CDPs.

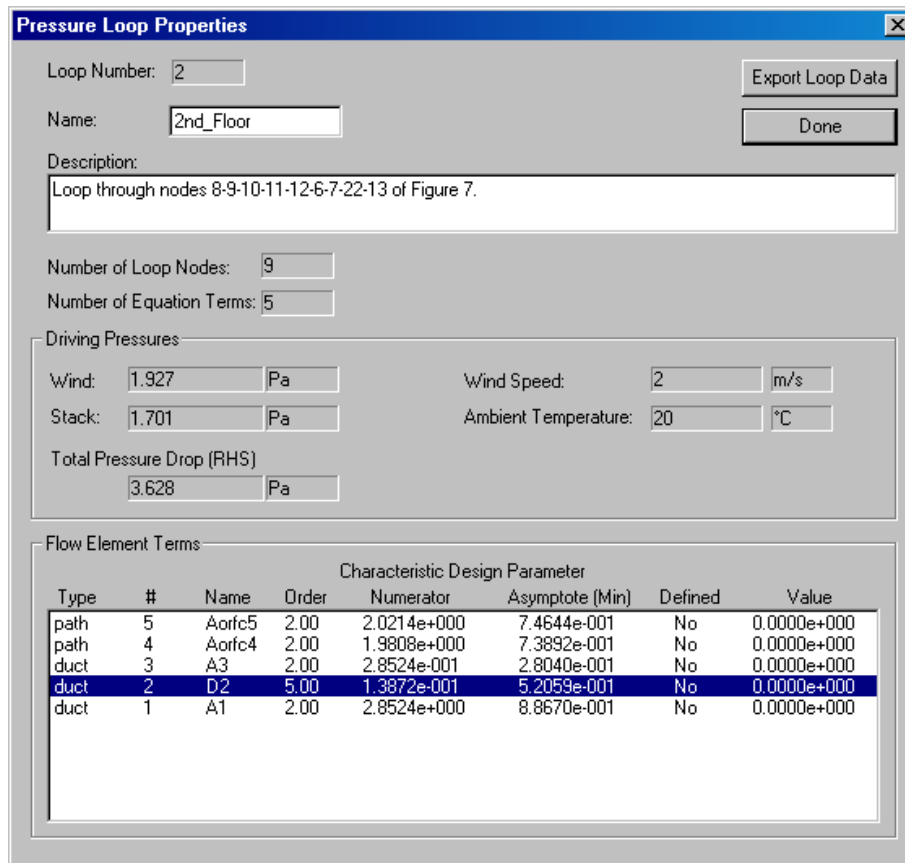


Figure 13 – Pressure loop properties window for Loop 2

After entering the information for Loop 2, the loop data are exported to a tab-delimited file which is pasted into the LoopDA spreadsheet template (click the icon below to view the Loop 2 information as it appears after being pasted into the LoopDA template).



LoopDA Loop
Worksheet1

Loop 2 has only five elements with undetermined CDPs (although $D2$, $A1$, and $A3$ are related). Figure 14 from the LoopDA template plot shows the sizing relationship between $D2$ and all other CDPs. From Figure 14, $D2$ will be set at 1.2 m. Basing the stack inlet and outlet areas ($A1$ and $A3$) on this diameter sets these areas at 1.1 m^2 (which is larger than the minimum requirements for these areas per the Loop 2 worksheet and Figure 14).

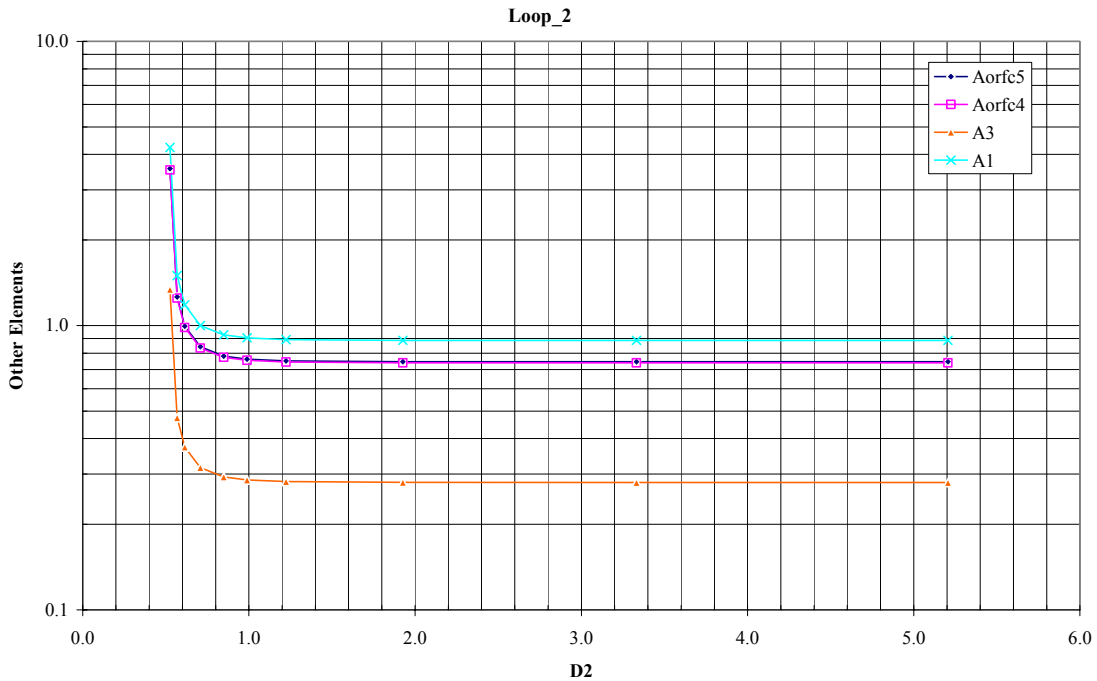


Figure 14 – Asymptotic relationships for Loop 2

Unlike Loop 1, Loop 2 still has undetermined CDPs. Returning to the LoopDA sketchpad, entering the parameters established for the stack duct and terminals ($D2$, $A1$ and $A3$), and exporting Loop 2 (see Figure 15 for the pressure loop properties) for a second time yields a second worksheet for this loop (click the icon below Figure 15 to view).

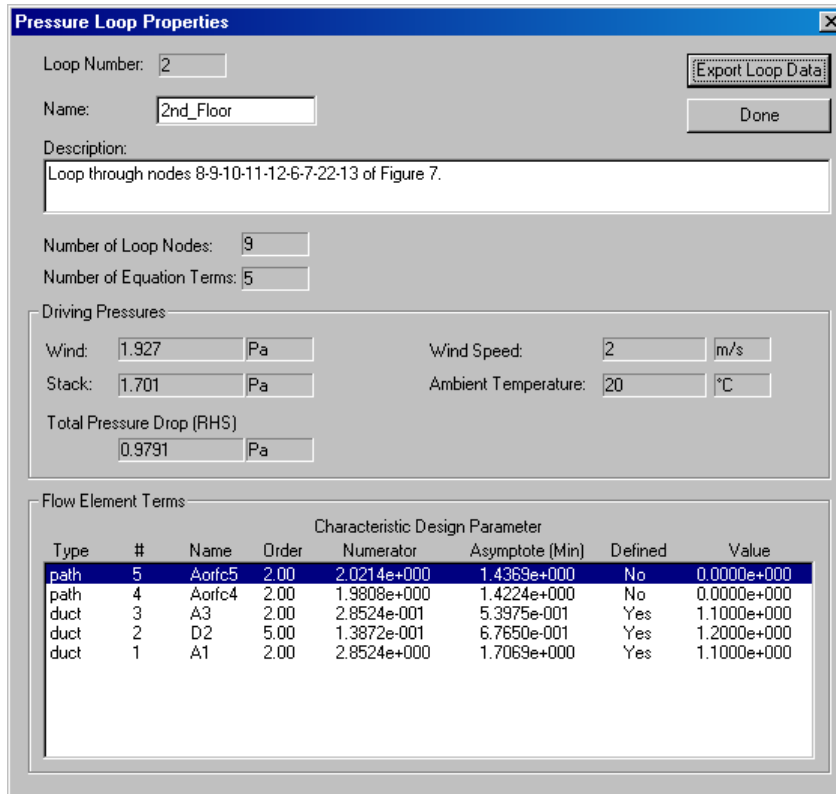


Figure 15 – Loop 2 pressure loop properties after setting the sizes of $D2$, $A1$ and $A3$



LoopDA Loop 2
Worksheet2

As seen in the worksheet and Figure 15, $A_{orf,c}$ (A_{orf5}) and $A_{orf,d}$ (A_{orf4}) remain to be selected. Figure 16 shows the asymptotic relationship between these remaining undetermined CDPs. From Figure 16, the inlet A_{orf5} will be selected as 2.0 m^2 , which sets the minimum outlet A_{orf4} also at approximately 2.0 m^2 .

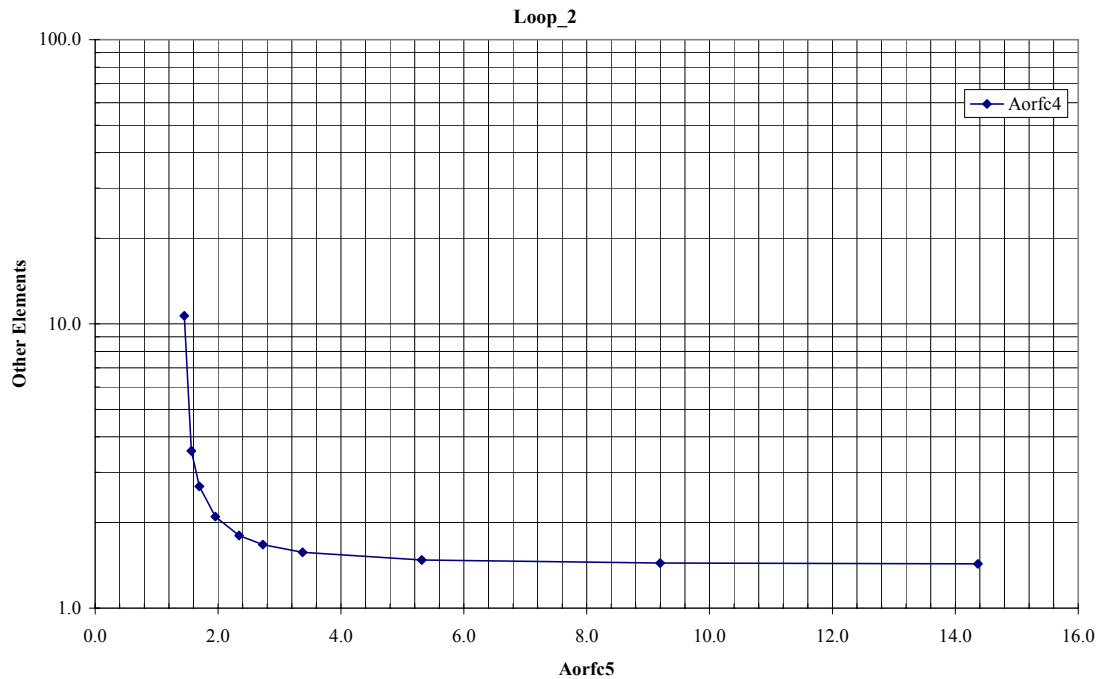


Figure 16 – Asymptotic relationship of remaining undetermined CDPs for Loop 2

4.3.3 Loop 3

Loop 3 consists of the same type of elements as Loop 2 – *inlet orifice a (Aorfc7)*, *outlet orifice b (Aorfc6)*, and the shared *stack exhaust g*. As seen in Figure 17, the previously defined stack CDPs are retained leaving only the inlet and outlet of *zone 1* to be defined. The LoopDA spreadsheet is similar to the second Loop 2 worksheet (click below to view). The asymptotic relationship between the undetermined CDPs *Aorfc6* and *Aorfc7* is shown in Figure 18. Selecting the outlet to be the same as for *zone 2* at 2.0 m² sets the minimum size for the inlet *Aorfc7* at approximately 1.3 m².



LoopDA Loop 3
Worksheet

Pressure Loop Properties
✕

Loop Number: Export Loop Data

Name: Done

Description:

Number of Loop Nodes:

Number of Equation Terms:

Driving Pressures

Wind: Pa Wind Speed: m/s

Stack: Pa Ambient Temperature: °C

Total Pressure Drop (RHS)
 Pa

Flow Element Terms

Type	#	Name	Order	Characteristic Design Parameter		Defined	Value
				Numerator	Asymptote (Min)		
path	7	Aorfc7	2.00	2.0214e+000	1.0996e+000	No	0.0000e+000
path	6	Aorfc6	2.00	1.9808e+000	1.0886e+000	No	0.0000e+000
duct	3	A3	2.00	2.8524e-001	4.1308e-001	Yes	1.1000e+000
duct	2	D2	5.00	1.3872e-001	6.0786e-001	Yes	1.2000e+000
duct	1	A1	2.00	2.8524e+000	1.3063e+000	Yes	1.1000e+000

Figure 17 – Pressure loop properties window for Loop 3

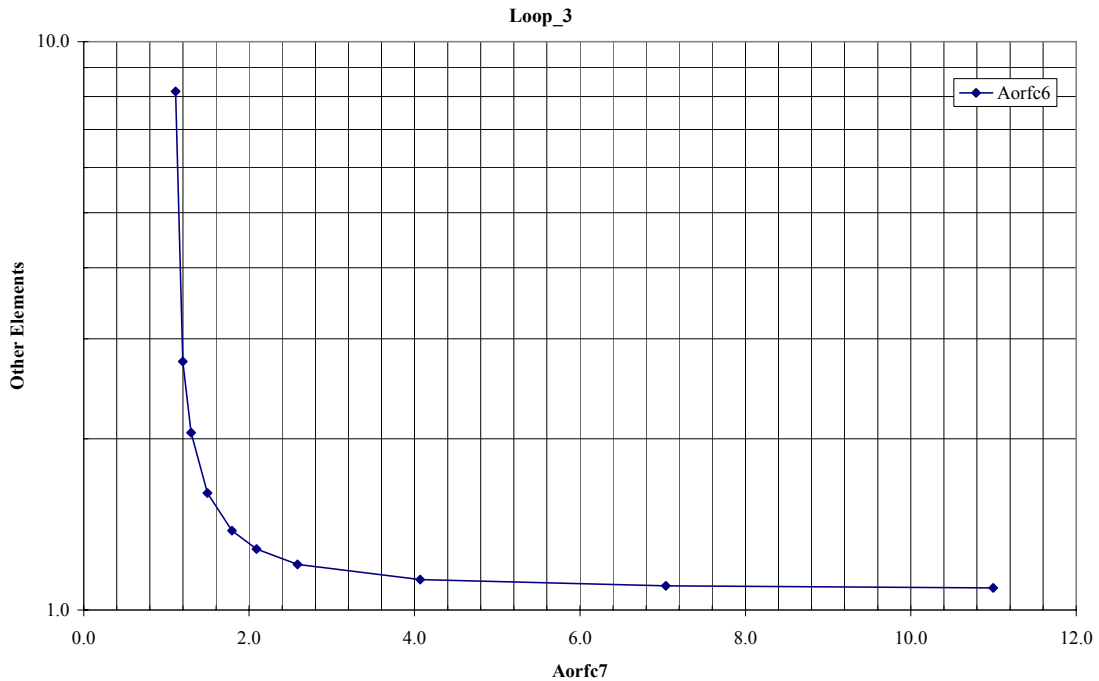


Figure 18 – Asymptotic relationships for Loop 3

4.3.4 Design Summary and Analysis

The completed design of the four ventilation loops is summarized below in Table 1.

Loop	Element	CDP		Size
		Figure 7	LoopDA	
1	Self-regulating inlet vent	C_e	Ce2	0.80
1	Stack terminal	$A_{orfc,g}$	Aorfc1	1.00
2	Inlet	$A_{orfc,c}$	Aorfc5	2.00
2	Outlet	$A_{orfc,d}$	Aorfc4	2.00
2	Stack inlet	$A_{stack\ in}$	A3	1.13
2	Stack diameter	$D_{stack\ duct}$	D2	1.20
2	Stack outlet	$A_{stack\ term}$	A1	1.13
3	Inlet	$A_{orfc,a}$	Aorfc7	1.30
3	Outlet	$A_{orfc,b}$	Aorfc6	2.00
3	Stack inlet	$A_{stack\ in}$	A3	1.13
3	Stack diameter	$D_{stack\ duct}$	D2	1.20
3	Stack outlet	$A_{stack\ term}$	A1	1.13
4	Self-regulating inlet vent	C_e	Ce3	0.80
4	Stack terminal	$A_{orfc,g}$	Aorfc1	1.00

Table 1 – Design values of sized components

LoopDA may now be used to analyze the completed design by performing simulations ranging from steady state under non-design conditions to a seasonal or annual analysis using TMY2 or other weather data for the location. One condition that could be analyzed is the potential for excess outdoor airflow under a winter condition. Referring back to Figure 8, an outdoor temperature of 5 °C and a wind speed of 8 m/s will be used. Also, the wall opening wind pressure coefficients will be increased to 0.6 to increase the impact of wind for this case. The indoor temperature is set to 20 °C for this case.

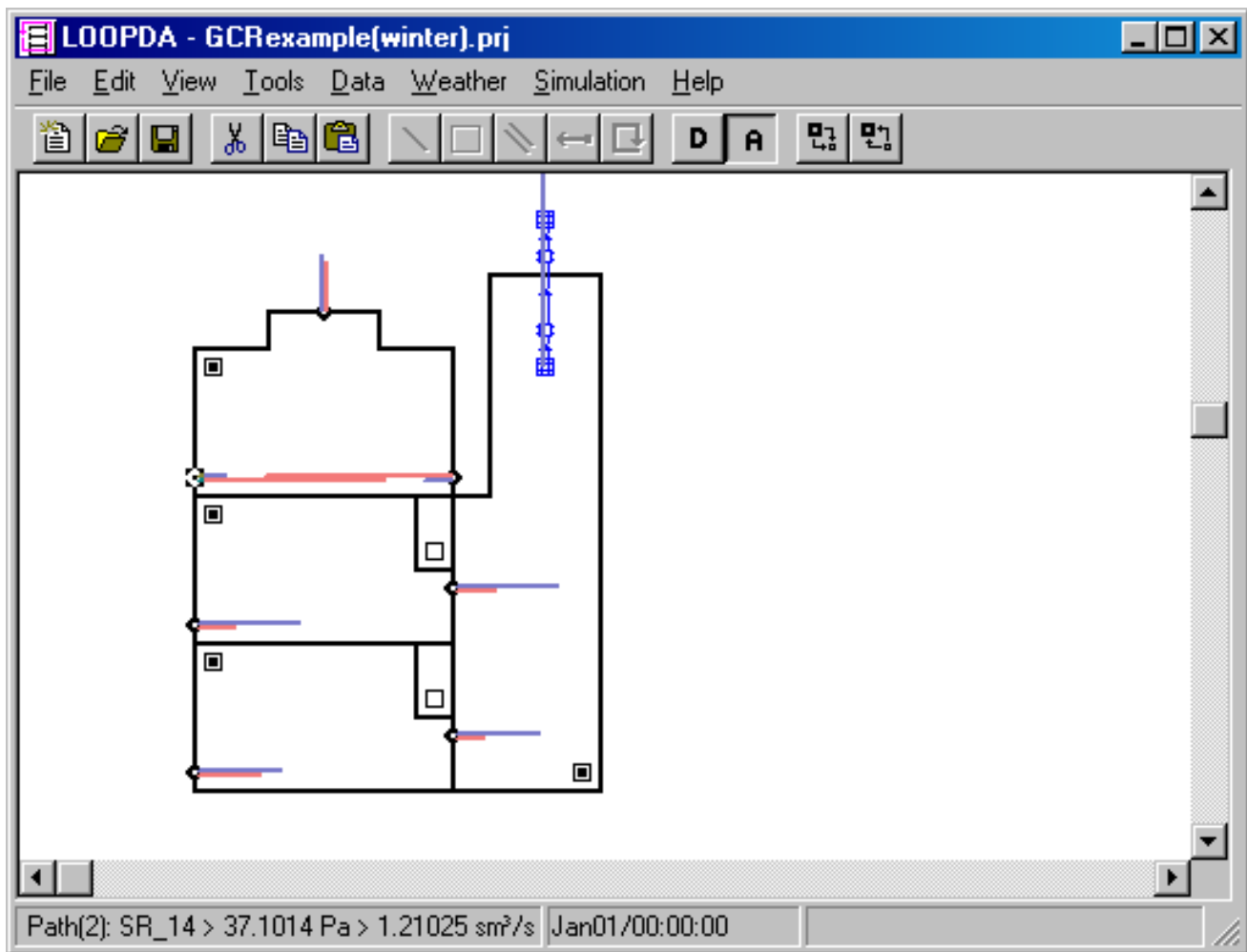


Figure 19 – Simulation results for winter condition analysis. Blue lines indicate direction and relative magnitude of airflow (note: status bar indicates a flow of 1.21 sm³/s for the self-regulating inlet vent)..

The results of the design analysis of a winter condition are shown in Figure 19. This analysis shows the risk of greatly over ventilating the space if no provision is made for altering the ventilation openings under a winter operating condition as the flow into zones 1 and 2 increases to 3 to 4 times the design flow. The self-regulating inlets perform better but the outdoor airflow still doubles from the design case. For a real building, the designer would likely specify a desired minimum winter ventilation flow and then use LoopDA in design mode to determine desired vent opening sizes in a winter mode. An operational strategy could then be established whereby, for example, half of the openings are used during winter operation.

5 CONCLUSION

This version of LoopDA was developed to demonstrate the implementation of the *Loop Equation Design Method* within an existing multi-zone modeling environment. It will serve to provide designers with a framework for implementing the design method in order to become familiar with the method, to explore the practicality of using this method within the overall natural ventilation system design process, and to provide feedback to the developers as to the potential for this tool for use by the design and analysis community.

As this is a preliminary version, it is reasonable that the potential for enhancements exists. Some potential enhancements have already been identified including: the implementation of a more diverse set of inverse flow component types, more robust user interface features and consideration for the design of mechanical components of hybrid ventilation systems. In general, inverse airflow elements are relatively easy to add to the existing environment. However, depending on the element type, the inverse solution to sizing some elements could prove to be more difficult than others, e.g., a polynomial fan curve. The user interface could perhaps be improved by eliminating the need for the external spreadsheet; providing automated population of analysis components based on design component sizes; verifying continuity of flow through components serving multiple loops; generation of reports summarizing design conditions and system design, enabling the application of a more diverse set of design constraints, e.g., requiring duct inlet, outlet and segments of the same size or providing a direct means to consider infiltration.

6 REFERENCES

1. Emmerich, S.J., W.S. Dols, and J.W. Axley. *Natural Ventilation Review and Plan for Design and Analysis Tools*. NISTIR 6781, National Institute of Standards and Technology. 2001.
2. Dols, W.S. and G.N. Walton. *CONTAMW 2.0 User Manual*. National Institute of Standards and Technology. DRAFT 2002.
3. Axley, J.W. *Application of Natural Ventilation for U.S. Commercial Buildings*. GCR-01-820 NISTIR 6781, National Institute of Standards and Technology. 2001.
4. Axley, J.W. *Residential Passive Ventilation Systems: Evaluation and Design*. AIVC Technical Note 54. Coventry, AIVC.
5. ASHRAE 2001. *ASHRAE Handbook - 2001 Fundamentals*, Atlanta, GA.
6. Irving, S. and E. Uys. *CIBSE Applications Manual: Natural Ventilation in Non-domestic Buildings*. 1997, CIBSE: London.
7. Marion, W. and K. Urban. *User's Manual for TMY2s*. National Renewable Energy Laboratory, 1995.

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