

Smart Vent[®] Hazard Evaluator Beta v. 1.3.2 Redefining the proper evaluation of safe flood venting

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EXECUTIVE SUMMARY

According to statistics from the Federal Emergency Management Agency (FEMA) National Flood Insurance Program (NFIP), floods are the number one natural disaster in the United States¹. Additionally, from 2011 to 2015 the average flood claim was over \$46,000 and the total flood insurance claims annually exceeded \$1.9 **billion** dollars (U.S.). Understanding proper methods of mitigating flood damage to the structural stability of an enclosure (basement and/or crawl space) that complies with national standards and best engineering practice has never been more important to the building owner, contractor and regulator.

Agnoli Engineering, LLC, in evaluating the Smart Vent[®] engineered, mechanically operated flood vents, reviewed available guidelines and engineering data related to their performance. What was not available was a simple method to evaluate the expected performance of Smart Vents[®] for a specific property with a standard rate of rise and fall of flood water of 5.0 feet per hour (1.52 meters per hour) per ASCE 24-14². This paper presents a tool developed by Agnoli Engineering with Microsoft[®] Office Excel[®] 2007 that allows an evaluator with minimal background in flood control and a basic understanding of a property to determine the sizing and level of protection provided by the Smart Vent[®] flood vents. The tool includes a conservative discharge coefficient of 0.44 as required by Table 2-2 in ASCE 24-14 and the minimum of one vent for every 200 square feet in the ICC Evaluation Service (ES) Report³.

The tool also allows the evaluation of alternative openings, including non-engineered openings. In the attached Appendix A, findings from the use of non-engineered openings, including a failure to meet ASCE 24-14 guidelines when set at the allowable 12 inches above grade, are discussed in detail. Additionally, non-engineered vents also failed to meet ASCE 24-14 guidelines if blocked by debris at nearly any degree (percentage).

¹ Federal Emergency Management Agency. "Flood Risks Nationwide." September 2013.

² American Society of Civil Engineers. "Flood Resistant Design and Construction (ASCE 24-14)"

³ ICC Evaluation Service. "ESR-2074 Smart Vent Automatic Foundation Flood Vents." February 2015 (exp. Feb. 2017)

Currently, the Smart Vent® is the only engineered vent that has a software spreadsheet that can produce a stage hydrograph for enclosure flooding, head differentials along an enclosure wall, and/or produce an external hydrostatic pressure curve. These tools are valuable to the various interests related to real estate ownership, including insurance and mortgage companies as well as construction code officials.

1.0 INTRODUCTION

The purpose of this White Paper is to provide the methodology and test case results of the Smart Vent Hazard Evaluator Beta developed by Agnoli Engineering, LLC. The Hazard Evaluator was developed to provide designers, owners, contractors, regulators and insurers with a tool to evaluate the performance of a proposed Smart Vent configuration against national standards. The principal design criteria included:

- ✓ Ease of use and ease of incorporating field data
- ✓ Transparency (equations and methodology)
- ✓ Flexibility for different and unique system layouts and configurations
- ✓ Detailed outputs for engineers and regulators

2.0 LITERATURE REVIEW

Agnoli Engineering sought to review both literature available directly from Smart Vent Products, Inc. specific to the dimensions and intended performance of the Smart Vent® devices but also available literature on federal requirements and third-party testing:

- ✓ American Society of Civil Engineers. "Flood Resistant Design and Construction (ASCE 24-14)." (2014). This document provides criteria for design as well as expected performance of engineered openings in Section 2.7.2.2.
- ✓ ICC Evaluation Service. "ESR-2074 Smart Vent Automatic Foundation Flood Vents." February 2015. This document provides an evaluation of physical operation and water flow through the Smart Vent® flood vents. It includes the minimum coverage (square feet) provided by each model number.
- ✓ Federal Emergency Management Agency. "Technical Bulletin 1, Openings in Foundation Walls and Walls of Enclosures." August 2008. This bulletin provides guidance on the National Flood Insurance Program (NFIP) regulations concerning the requirement for openings in below Base Flood Elevation (BFE) foundation walls and walls of enclosures for buildings located in Flood Zones A, AE, A1-A30, AR, AO, and AH.

3.0 SOLUTION

The Smart Vent Hazard Evaluator Beta tool was developed using Microsoft® Office Excel® to simplify the experience for novice users. The tool consists of three worksheets: Smart Vent® Tool, Model Lookup, and Calculations.

3.1 Smart Vent® Tool Worksheet

The Smart Vent® Tool worksheet provides the user an input interface and returns the results. The required inputs include:

- ✓ Smart Vent® Model or Non-Engineered Opening Type;

- ✓ Number of Vents;
- ✓ Flood Water Properties (fresh water or salt water);
- ✓ Percent Obstruction;
- ✓ Installed Height Above Grade;
- ✓ Smart Vent® Discharge Coefficient
- ✓ Non-Engineered Opening Parameters (width, height, cover)
- ✓ Enclosure Area;
- ✓ Enclosure Depth Below Grade;
- ✓ Enclosure Height Above Grade;
- ✓ Grade Elevation;
- ✓ Base Flood Elevation; and
- ✓ Rate of Flood Rise.

Most of the inputs can be obtained from a standard FEMA Elevation Certificate and rate map. The rate of rise of surround flood water is given as five feet per hour per ASCE Standard 24-14; however, it can also be obtained from an available hydraulic analysis. The evaluation time increment can be adjusted to encompass the full flood duration as needed. The Smart Vent® model name is a pulldown menu that populates the dimensions provided on the Model Lookup Worksheet.

The number of vents and installed height above grade are the two primary design parameters. The user can adjust these parameters until the minimum design criteria are met:

- ✓ Minimum number of vents (2) per Technical Bulletin 1: "each enclosed area is required to have a minimum of two openings on exterior walls to allow floodwaters to enter directly."
- ✓ Minimum number of vents to meet the area coverage rating per vent as provided in Table 1 of ICC-ES Report ESR-2074.
- ✓ Maximum height of opening above grade per Technical Bulletin 1: "the bottom of each opening is to be located no higher than 1 foot above the grade that is immediately under each opening."
- ✓ Maximum head differential requirements per ASCE 24-14: "the performance of engineered openings shall ensure that the difference between the exterior and interior floodwater levels shall not exceed 1 foot." To check this requirement, the tool verifies that the maximum head on the wall above grade prior to equalization is less than 1 foot. When flood waters rise to the adjacent grade elevation prior to the flood vent activation, the enclosure would begin as dry. The additional loading on the wall beyond the typical foundation design would be expected to occur when the flood waters are above the adjacent grade. Therefore, the tool checks that the Smart Vent® configuration entered by the user allows the enclosure to fill up fast enough for the head differential between the interior and exterior flood levels to be less than 1 foot.

The Smart Vent Tool worksheet provides the following results:

- ✓ Orifice Discharge Coefficient used in the calculations
- ✓ Time for enclosure flooding to equalize with external flood
- ✓ Time to fill the enclosure
- ✓ Maximum enclosure flood depth
- ✓ Maximum head differential between flood levels internal and external to wall

- ✓ Maximum head on wall above grade
- ✓ Maximum head on wall above grade prior to equalization
- ✓ Maximum uplift pressure
- ✓ Maximum lateral hydrostatic force on enclosure wall
- ✓ Lateral hydrostatic force on enclosure wall during maximum head differential
- ✓ Maximum uplift (buoyancy) force due to hydrostatic pressure
- ✓ Stage hydrograph figure
- ✓ Head differential between flood levels internal and external to wall figure
- ✓ External hydrostatic pressure above grade figure

If a design criterion is not met, the tool provides suggestions to the user to modify the configuration (i.e. add vents or adjust installed height above grade).

3.2 Model Lookup Worksheet

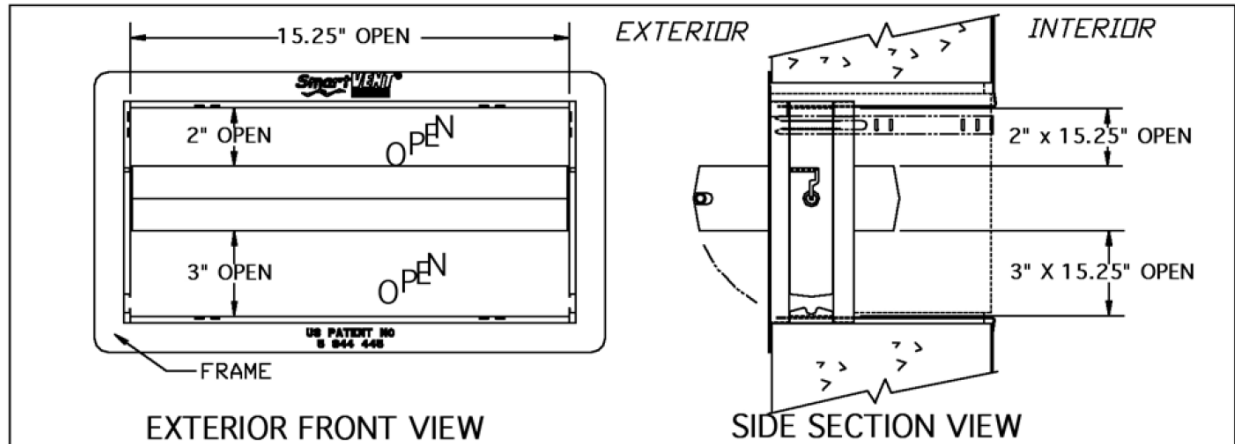
The Model Lookup worksheet provides the lookup table of dimensions for each Smart Vent® model. The dimensions include the width, vent opening heights above and below the door, vent door depth, and height above vent invert for activation. The dimensions associated with the Smart Vent® model chosen by the user are populated on the Smart Vent® Tool worksheet and Calculations worksheet.

3.3 Calculations Worksheet

The Calculations Worksheet contains the calculations performed by the tool. The tool evaluates the performance of the Smart Vent® configuration entered by the user with a quasi-unsteady approach. The tool calculates the rising flood elevation, inflow through the vents, and resultant flood depth in the enclosure for each time step during the flood rise until the flood level in the enclosure equals the external flood elevation. Once the internal and external flood elevations equalize, the internal and external flood elevation rise at the same rate for the remainder of the simulation. Based on these results, the tool calculates the results provided on the Smart Vent® Tool worksheet.

The tool calculates the flow through each Smart Vent® at each time step. The flow for each Smart Vent® is then multiplied by the number of vents to calculate the total inflow into the enclosure. When the Smart Vent® is activated, the door swings open to provide a lower and an upper slot opening. Figure 1 below provides typical dimensions of the openings through Smart Vent® when activated.

Figure 1 – Smart Vent Dimensions



Reference: Smart Vent, Inc.: Certification of Engineering Opening (July, 2007)

The tool was developed to consider the changing flow conditions that would be expected through the Smart Vent as the flood level rises, the vent activates, flood waters flow through first the lower slot then upper slot, and the enclosure fills. The Smart Vent activates when the flood level reaches 1.5 inches above the invert of the vent. When the flood level is less than 1.5 inches above the invert of the vent, the vent is assumed to be closed and the tool assumes no inflow for the time step.

For time steps when the Smart Vent® is activated and the flood level is below the top of a slot opening (either lower or upper), the tool assumes weir flow through the appropriate opening using the broad-crested weir equation⁴:

$$Q = 2.64 b * h^{3/2} \quad \text{Equation 1}$$

Where: Q = discharge (cfs)
 b = width of slotted opening
 h = head (feet)

The discharge coefficient (2.64) across the weir was selected as the most conservative for a "broad-crested" weir from the reference below (4). However, the weir discharge coefficient is adjusted when a screen is installed on the opening. When the user selects "Yes" regarding a screen in place, the tool adjusts the weir discharge coefficient (CW) with the following equation:

$$C_w = \frac{C_{OS} \times 2.64}{C_{OR}}$$

Where: C_w = Weir discharge coefficient
 C_{OS} = Orifice discharge coefficient of an opening with a screen (0.2)
 C_{OR} = Orifice discharge coeff. of a rectangular opening with a long horizontal axis (0.4)

The tool therefore uses a weir discharge coefficient of 2.64 when no screen is in place, and a weir discharge coefficient of 1.32 when a screen is in place. The weir discharge coefficient adjustment is provided in cell H23 on the calculations sheet.

⁴ King and Brater. "Handbook of Hydraulics." 1977 (5th Edition).

When the flood level is above top of a slot (either upper or lower) the tool treats each slot as an orifice using the equation⁵:

$$Q = C_o * A (2gH)^{1/2} \qquad \text{Equation 2}$$

Where: Q = discharge (cfs)
 Co = discharge coefficient (**0.6**) per Table 2-2, ASCE 24-14
 A = Opening Area (square feet)
 g = acceleration due to gravity (32.2. feet/second²)
 H = head (feet)

The coefficient of discharge from Table 2-2 in ASCE 24-14 normally used for a “Rectangular, long axis horizontal, short axis vertical, unobstructed during design flood,” is designated as **0.4**. However, a footnote allows for “different coefficients of discharge ... (1) where a designer has performed detailed, opening-specific calculations, a coefficient of discharge up to **10% different** than given in Table 2-2 shall be permitted; or (2) where laboratory testing or numerical modeling of flow through the opening has been conducted, the resulting coefficient of discharge shall be permitted. In no case shall a coefficient of discharge >0.60 be permitted.”

Unsubmerged orifice coefficients are typically 0.60 to 0.61 for fully contracted orifice openings for circular, square or rectangular shape⁴ The tool allows the user to select a coefficient of 0.44, 0.60, and 0.20 to evaluate the sensitivity of the discharge coefficient on their selected configuration. If a non-engineered opening is selected, the model will not use the Smart Vent discharge coefficient parameter.

The user can also select non-engineered rectangular, square, circular, and other shaped flood openings from the pull-down list in addition to Smart Vent products. When a non-engineered opening is selected, the user must enter the non-engineered opening parameters including the width, height, net opening area, and whether the opening has a cover. The tool will then use the non-engineered opening input parameters to select the appropriate discharge coefficient per ASCE 24-14 as shown in Table 1 below. Per ASCE 24-14, an opening shall be classified as partially obstructed (discharge coefficient of 0.20) if louvers, blades, screens, grilles, faceplates, or other covers or devices are present during the design flood. Therefore, if there is a cover on the opening, the tool will select a discharge coefficient of 0.20 regardless of the opening shape. Otherwise, if there is no cover on the opening, the tool will select the appropriate unobstructed discharge coefficient based on the opening’s shape from Table 1. The model will not use the non-engineered opening parameters if a Smart Vent product is selected.

⁵ As above (Ref. 4)

Table 1 – Flood Opening Coefficient of Discharge^a (ASCE 24-12 Table 2-2)

Opening Shape and Condition	C
Circular, unobstructed during design flood ^b	0.6
Rectangular, long axis horizontal, short axis vertical, unobstructed during design flood	0.4 ^c
Square, unobstructed during design flood	0.35
Rectangular, short axis horizontal, long axis vertical, unobstructed during design flood	0.25 ^d
Other shapes, unobstructed during design flood	0.3
All shapes, partially obstructed during design flood	0.2

^a Different coefficients of discharge shall be permitted: (1) where a designer has performed detailed, opening-specific calculations, a coefficient of discharge up to 10% different than given in Table 2-2 shall be permitted; or (2) where laboratory testing or numerical modeling of flow through the opening has been conducted, the resulting coefficient of discharge shall be permitted. In no case shall a coefficient of discharge >0.60 be permitted.

^b Openings shall be classified as partially obstructed if louvers, blades, screens, grilles, faceplates, or other covers or devices are present during the design flood.

^c When the horizontal dimension is twice or more the vertical dimension, use 0.4; as the dimensions approach a square, interpolate from 0.4 to 0.35.

^d When the horizontal dimension is half or less the vertical dimension, use 0.25; as the dimensions approach a square, interpolate from 0.25 to 0.35.

Reference: ASCE 24-12 Table 2-2

The user can evaluate if the opening were to be obstructed by entering the percent obstruction (type in decimal format) into the tool. Per ASCE 24-14 and as shown in Table 1, a discharge coefficient of 0.20 should be used for all shapes when partially obstructed. When the user enters a percent obstruction greater than zero, the tool assigns a discharge coefficient of 0.20. The percent obstruction entered by the user is then used to reduce the opening area used in the orifice equation and opening width used in the weir equation. For non-engineered openings, the percent obstruction will reduce the total opening area by the user input value. For Smart Vent openings, lower and upper openings are each reduced by half of the total percent obstruction by the user input value. During weir flow, the percent obstruction reduces the opening width by the user input value to represent the reduced conveyance through the vent.

The tool provides numerical modeling of flow through the opening and checks that the modeled flow calculated using Equation 2, is less than the ideal flow. If the model flow is less than the ideal flow, then the discharge coefficient used in the model flow calculation (Equation 2) is appropriate. The ideal flow equation for a rectangular orifice per the Handbook of Hydraulics (Brater and King) is given as:

$$Q_t = 2/3 * L * (2g)^{0.5} * (h_2^{3/2} - h_1^{3/2}) \quad \text{Equation 3}$$

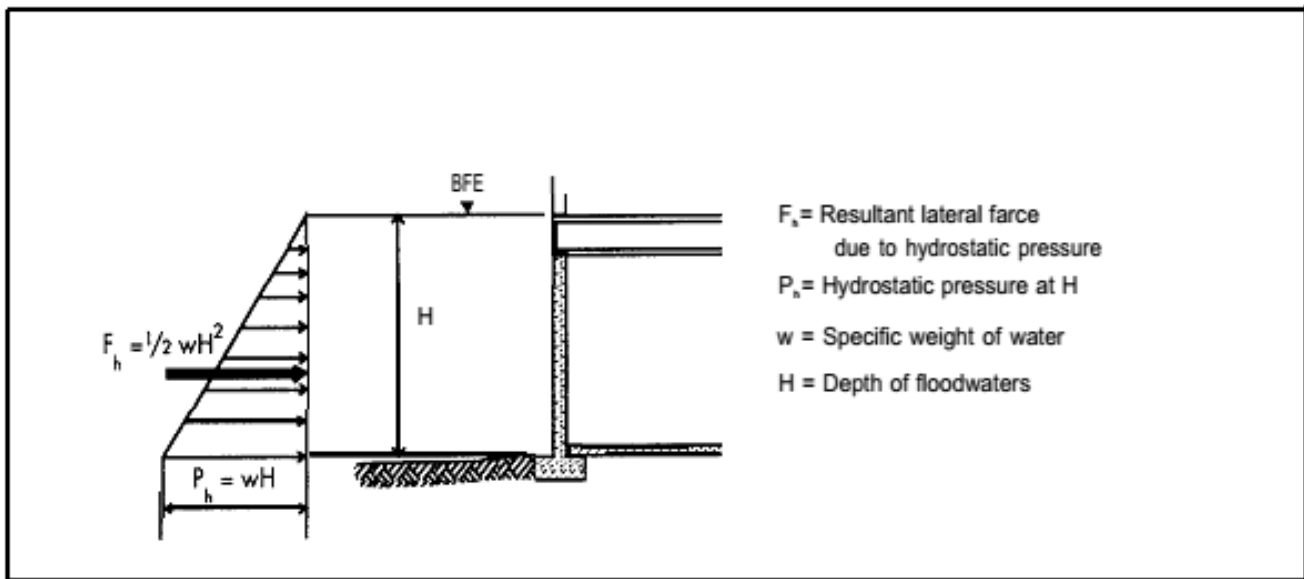
Where: Q_t = discharge (cfs)
 L = Width of Orifice (feet)
 g = acceleration due to gravity (32.2. feet/second²)
 h_1 = head above top of orifice (feet)
 h_2 = head above invert of orifice (feet)

The tool calculates the ideal flow for the lower slot opening and upper slot opening for each timestep. These flows are then combined to provide the total ideal flow through a single vent. The tool then checks if the ideal flow is greater than the model flow. This analysis shows that the model flow is less than the ideal flow. Therefore, Agnoli Engineering, LLC recommends that discharge coefficient of 0.6 is appropriate for Smart Vent Products, Inc.

The maximum hydrostatic/uplift pressure and maximum lateral hydrostatic force on the enclosure wall are calculated using the equations in Figure 2 below. The maximum lateral hydrostatic force is the resultant lateral force due to hydrostatic pressure for the full head from the BFE to the base of the enclosure wall. The tool also uses the equation in Figure 2 to calculate the lateral hydrostatic force on the enclosure wall during the maximum head differential. This values provides the user with the maximum lateral force acting externally on the wall during the flood event prior to equalization of the interior and exterior flood levels. The tool also calculates the resultant vertical (buoyant, or uplift) force due to hydrostatic pressure on the enclosure using the equations in Figure 3 below.

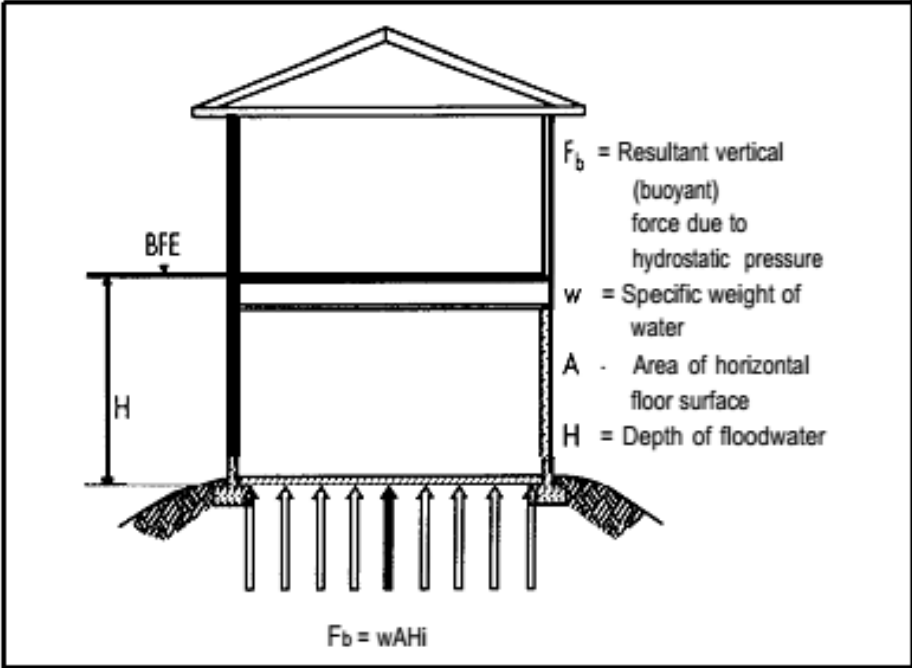
The user has the option to select fresh water or salt water for the hydrostatic pressure and loading calculations. The tool will use the appropriate specific weight of water based on the user's selection (62.4 lb/ft³ for fresh water and 64 lb/ft³ for salt water).

Figure 2 – Lateral Hydrostatic Pressure and Force



Reference: FEMA NFIP Technical Bulletin 1-93 (1993)

Figure 3 – Uplift/Buoyancy Force



Reference: FEMA NFIP Technical Bulletin 1-93 (1993)

4.0 TESTING AND VALIDATION

The Smart Vent® Hazard Evaluator Beta was run with eight test cases to evaluate various enclosure configurations. Table 1 summarizes the enclosure configurations assumed in each test case.

Table 2 – Test Cases

Test Case	Diagram *	Height of Enclosure (feet)	Subgrade (feet)
1	2	8	0.4
2	2	8	3.3
3	9	3	0.8
4	9	3	1.6
5	9	3	0.5
6	7	6	0
7	7	8	0
8	8	3	0

*FEMA Elevation Certificate Building Diagram Number

The following parameters were assumed for all of the test cases (Table 3):

Table 3 – Input Parameters

Enclosure Area:	1,000	square feet
Grade Elevation:	100	feet
Base Flood Elevation:	105	feet
Rate of Flood Rise:	5	feet/hour
Flood Water Type:	Fresh Water	

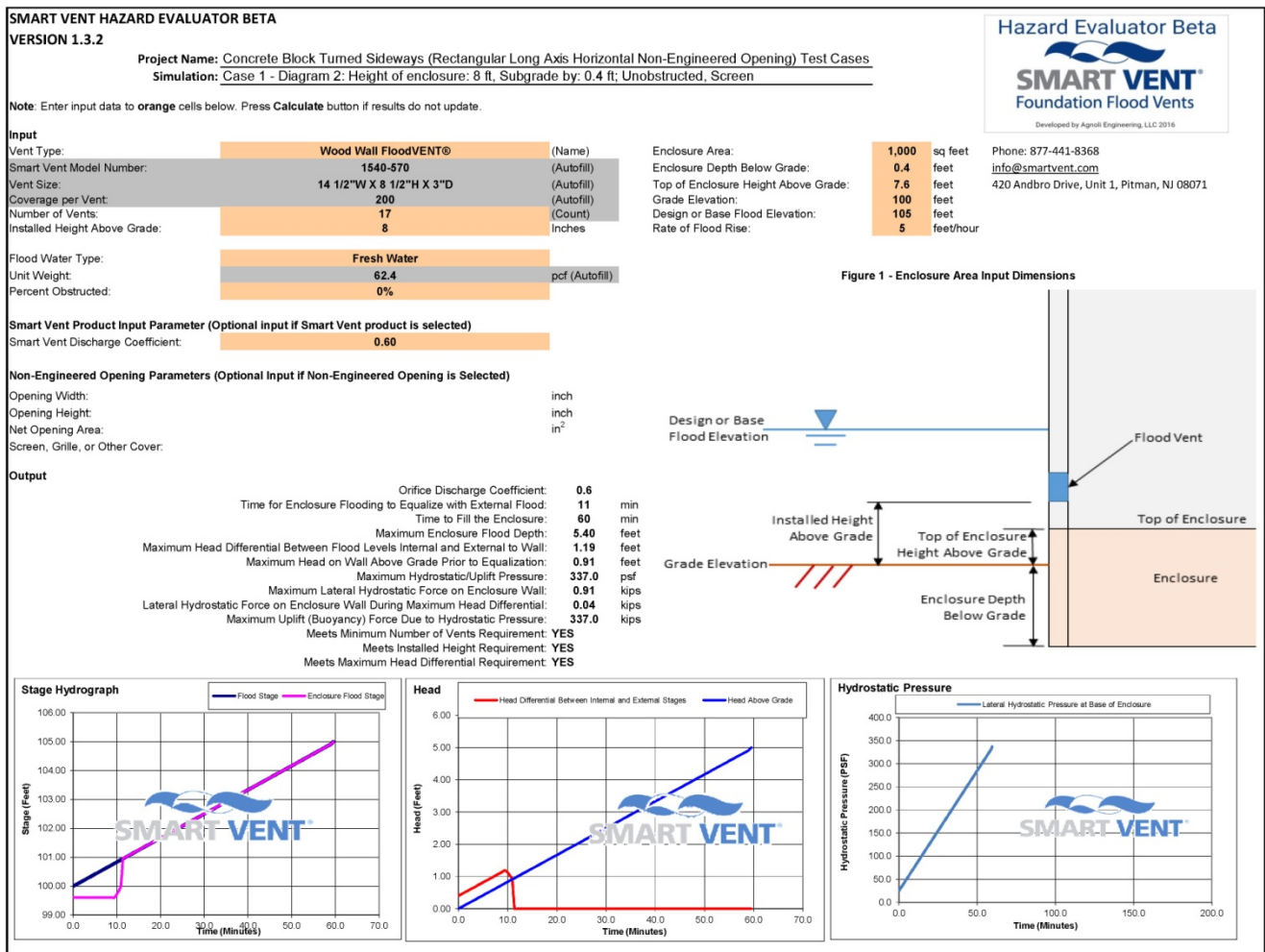
The number of vents and installed height above grade inputs were adjusted to meet the minimum design criteria for each test case.

The results of the test case runs are provided in Table 4. For each run, various combinations of number of vents and installed height above grade were evaluated to find the minimum number of vents required to meet the design criteria. Per ESR-2074, the enclosed area coverage per vent is 200 square feet. The test cases assumed a 1,000 square feet enclosed area and given the recommended coverage in ESR-2074, a minimum of 5 vents. The results support the coverage provided in ESR-2074 for each test case with the appropriate installed height above grade chosen by the designer.

Table 4 – Results

Test Case	Height of Enclosure (feet)	Subgrade (feet)	Number of Vents	Installed Height Above Grade (inches)	Max Head on Wall Above Grade Prior to Equalization (feet)	Time for Enclosure to Equalize with External Flood (minutes)
1	8	0.4	5	8	0.9	12
2	8	3.3	5	7	1.0	13
3	3	0.8	5	8	1.0	11
4	3	1.6	5	8	1.0	12
5	3	0.5	5	8	1.0	12
6	6	0	5	8	1.0	0
7	8	0	5	8	1.0	0
8	3	0	5	8	1.0	0

Figure 2 – Test Case 1 Screen Image of the Smart Vent Hazard Evaluator Beta



5.0 CONCLUSIONS

The Smart Vent® Hazard Evaluator Beta is able to verify that the current sizing practice for the Smart Vent® product is adequate. During a rate of flood water rise of 5 feet per hour recommended by ASCE 24-14, the tool shows that with the appropriate configuration, the Smart Vents® allow the enclosure to fill up fast enough for the head differential between the interior and exterior flood levels to be less than 1 foot. This small differential will significantly reduce the potential for structural damage as a result of hydrostatic pressure on an enclosure wall. The user can further refine their analysis with this tool by using a rate of rise based on a hydraulic model. This tool should be used to evaluate site specific deployment of each Smart Vent® product and can be used to quantify the likely reduction in structural damage to an enclosure and reduction in financial loss.

Additionally, the tool can be used to evaluate existing installations that include non-engineering openings and the need for additional venting to meet the above requirements.