LV-11-016

Analysis Tools and Guidance Documents for Evaluating and Reducing Vulnerability of Buildings to Airborne Threats—Part 2: Comparison of Tools

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ABSTRACT

Assessing and reducing vulnerability of building occupants to intentional indoor airborne releases of chemical and biological agents has acquired some importance in the past two decades. This paper reports on the evaluation and comparison of a set of available tools (described in the companion paper) that have been developed for practical and pragmatic use by building security professionals, consulting engineers, building owners, and maintenance personnel to evaluate the vulnerability of a building and determine the effect of implementing specific countermeasures. These tools have been applied to a few carefully selected buildings so that their responses can be evaluated both in terms of the risk assessment aspect as well as a portion dealing with evaluation of resiliency measures. The ease in using the tools, the quantity and specificity of the suggestions they provide, and the extent to which the responses differ between tools are issues that have been investigated and are presented in this paper. Also articulated are suggestions for future modifications to these tools in order to make them more user-friendly while enhancing their capabilities (such as being able to tailor the tools to a specific building rather than to a generic type, compute risk explicitly, compute the consequences of the event, etc.).

BACKGROUND

Part I of this paper (Reddy et al. 2011) presents findings of a scoping study undertaken to review existing literature, available protocols, and analysis tools meant to first evaluate current state of risk of building occupants from chemical and biological (CB) threats, and then suggest mitigation measures to reduce vulnerability (Bahnfleth et al. 2008). The literature examined was specific to indoor airborne threats and dealt with technologies and design practices for enhancing resiliency via ways of securing the building's heating, ventilating, and air-conditioning (HVAC) systems. Gaps in the open literature were also discussed. The CB threat and metrics to quantify them were identified and reviewed, and it was found that though a number of reasonable performance measures have been proposed by various organizations and researchers, all have limitations, and no consensus standard has as yet emerged. In terms of recommended technologies and design practices for enhancing resiliency, there are a fair number of documents that provide guidance (largely repetitive), but their recommendations are mainly heuristic and are rarely supported by quantitative data. Only a few studies have quantitatively, via simulations and/or field trials, analyzed the effectiveness of the resiliency measures advocated. The scoping study also identified and discussed gaps in the various analysis methods, tools, and simulation programs meant to evaluate building security and to mitigate against these threats. Though several of the evaluation guidelines have appeared in the published literature for years, not a single paper/report was found that evaluates these in terms of practical applicability and relevance against one another or in absolute terms. This paper reports on findings of a study undertaken to address this deficiency.

TOOLS TO BE EVALUATED

The following five tools were identified and described in some detail by Reddy et al. (2011) as useful to practicing engineers and field professionals to obtain practical and pragmatic risk assessment and guidance on how to enhance resistance of their facilities to indoor airborne threats:

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1. The HVAC Building Vulnerability Assessment Tool (BVAT), developed by the Rhode Island Department of Health (RIDH 2004)
2. The Building Assessment Checklist (BAC), developed by the Los Angeles County Department of Public Health (Fielding et al. 2006)
3. The Building Vulnerability Assessment and Mitigation Program (BVAMP), developed by the Lawrence Berkeley National Laboratory (LBNL 2005)
4. The Chemical/Biological Building Protection Tool (CBT), developed by the United Technologies Research Center (UTRC 2004)
5. The document/software program, FEMA 452, developed by the Federal Emergency Management Agency (FEMA 2005)

METHODOLOGY

The second objective of this paper is to report on our observations and conclusions in evaluating the above-described tools in terms of applying them to actual buildings. This section will describe our methodology for making such an assessment and state the criteria involved.

1. *Identify tools.* The methodology for evaluating guidance and risk assessment tools must first start by identifying those that are developed to a stage where they are actually tools that can be used in an actual and specific situation, as against general analysis procedures or methodologies or case study examples. The subset of tools to be evaluated has already been identified, and they have been stated in the section above.
2. *Evaluation criteria.* The following criteria were identified as appropriate to evaluate the selected tools:
   - What information is needed and whom from the facilities staff is best able to provide this information?
   - Would the services of specialists be required to obtain it?
   - How difficult is it to get the necessary information needed by the tools?
   - How long does it take to insert the necessary information in each tool?
   - How do they describe a building's vulnerability?
   - What types of categories or distinct subsystems are used?
   - How logical are they?
   - What type of guidance do they provide and what is its quality?
   - How comprehensive and building-specific are the risk evaluations?
   - How do the recommendations generated by the tools compare with one another?
   - How sensitive are the recommendations to changes in the inputs?
   - How user-friendly and intuitive are the tools in their inputs?
   - How opaque/transparent are the tools in how they determine or assess risk and propose mitigation measures?
   - How sound are the suggested enhancements to reduce vulnerability?
3. *Risk assessment questionnaire.* The first step in evaluating these tools was to become familiar with each of them in terms of how their checklist or questionnaires were grouped, and which specific questions were asked. Since there was a great deal of overlap in questions among these tools, we felt the need to develop a single, concise checklist containing all the questions needed for all tools, and which could be administered only once to the building owner/manager. Having such a compact vulnerability questionnaire greatly simplifies the process of obtaining building information, and is more appealing to facility managers filling out such a questionnaire. The questions relating to airborne contaminant attacks were extracted from each tool and compiled into one comprehensive questionnaire. Next, all redundant questions were eliminated to create a compact vulnerability questionnaire that is geared specifically toward airborne contaminant attacks (this questionnaire can be found in Bahnfleth et al. [2008]).
4. *Identification of representative buildings.* A final and important step in the evaluation procedure was to identify a few buildings to which the questionnaires could be applied. The scope was limited to noncritical buildings, i.e., buildings for which security from terrorist incidents is not normally a design consideration, and so no special protective measures are incorporated in their designs. Then, a logical choice is to select buildings that fall under the office and hotel categories. The former comprises by far the largest portion of building stock, while the latter can be viewed as one where a large number of occupants could be adversely affected.

RESULTS OF EVALUATING THE TOOLS

Representative Buildings

Buildings on university campuses are subject to a heightened risk of attack compared to most buildings because of their high visibility and open access. Four buildings were selected whose characteristics are representative of a large portion of building stock that would qualify as noncritical importance level (see Table 1): two each from two university campuses, one in an urban setting and another in a semi-rural university town setting. One building is a typical residence hall on the urban campus. Residence halls usually have fairly simple HVAC systems and repeated floor plans. They also have a high occupancy of students, making them a significant target for a potential attack. Two buildings are typical office/classroom buildings, while the fourth one is a large auditorium. These

Table 1. Description of Buildings Evaluated

Type of Building	Dormitory	Office/ Classroom	Office/Classroom	Auditorium
Location	Urban campus	Urban campus	Semi-rural campus	Semi-rural campus
Gross floor area	108,535 ft^2	29,444 ft^2	31,1000 ft^2	45,000 ft^2
Number of floors	7	4	3 floors + mechanical room in basement	—
Total occupancy	300	30–40 office personnel, 300–50 students in class	Normal occupancy of 140 + up to 170 floating students and professionals	2595 seats + ticket office + ushers+ concession workers
HVAC system	Water-source heat pump in each suite, centralized ventilation, AHU with heat recovery	Rooftop-packaged units with VAV and gas heat	VAV chilled-water AHU with hot-water heating coils	Multiple VAV and CAV chilled-water AHUs with hot-water heating coils
Other information	4–6 person per suite	Mixed office-classroom	—	—

Table 2. Format and Categories of Evaluated Tools

Tool	Tool Format	Categories	# Questions	# Questions on HVAC/IAQ
BVAT- Rhode Island	MS Word	Types of air ventilation/conditioning, air-handling units, air intakes, recirculation modes, mechanical rooms, filtration specs, system O&M	42	42
BAC- Los Angeles	MS Word	Architecture features (entry, lobby, mail, air zone separation, windows, walls, etc.), mechanical design features (fresh outdoor air intakes, HVAC mechanical room, HVAC unit), interior security measures, personnel security, evacuation, shelter in place, purging, emergency personnel	92	92
BVAMP- LBNL	Java program	Emergency response, HVAC systems, building access, HVAC controls	114	114
FEMA	MS Word	Site, architectural, structural, envelope, utility systems, HVAC, plumbing and gas systems, electrical systems, fire alarm systems, communication and IT, equipment O&M, security systems	341	80
CBT- UTRC	Visual Basic	Physical security, building configuration, monitoring, HVAC, training and communication, air intake design	60	60

four buildings were chosen because they are all typical buildings that make good case studies since they would apply to a large portion of existing buildings that qualify as noncritical buildings.

The director of plant maintenance in the Facilities Management Department at the urban university campus, and the senior mechanical engineer in the Office of the Physical Plant at the semi-rural campus were interviewed to obtain the answers to the questions asked by each assessment tool. The director of plant maintenance and the senior mechanical engineer answered all the questions in the compact questionnaire for the four buildings being assessed. With these answers, each tool can be applied to all of the buildings.

Evaluation in Terms of Overall Capability

Table 2 provides a summary of the characteristics of the tools: the tool format (Microsoft® Word document, software program, etc.), the category breakdown of each tool's questionnaire, the number of questions, and the number of questions that are related to the HVAC system and airborne agent attacks. From this table, it can be seen that each tool is somewhat unique in structuring the questionnaire for assessing a building's vulnerability toward airborne attacks.

Our judgment and opinions of how the various tools compare against each other in terms of the various characteristics described earlier to evaluate the tools are assembled in

Table 3. Comparison of Evaluated Tools

Tool	Time Required/Ease of Use	Type of User Input	Basis of Evaluation of Building Vulnerability	Unique Features
BVAT—Rhode Island*	Little time required to complete checklist. Simple to use, self-explanatory. May need qualified assessors to answer some questions.	Mostly yes/no with some short answer questions	No visual/numerical output, but user acquires a sense of building vulnerability by answering questions and reading recommendations.	
BAC—Los Angeles*	Ditto	OK/not OK Inputs	Ditto	
BVAMP—LBNL	Ditto	Yes/no Inputs	Ditto	Questions asked are dependant on answer to previous questions. Program eliminates questions that do not apply after a certain answer has been provided.
FEMA*	Complex database capable of storing a large amount of information. Significant time required to answer all questions and fill out all matrices. Time required to read FEMA document. Need qualified assessors to answer some questions.	Descriptive input in the user's own words.	User selects weights from given tables, which provide a quantitative index of risk that is color-coded.	Database format (image and information storage), ability to link databases, risk matrices, ability to organize and prioritize noted vulnerabilities.
CBT—UTRC	User-friendly program, relatively self explanatory. Little time required to answer questions. Some time required to evaluate recommendations and explore other features. May need qualified assessors to answer some questions.	Drop-down menu of preset answers (in hierarchy of security level) to each question.	Weighted matrix calculated depending on answers showing vulnerability that is color-coded.	Automatically produced color-coded matrix, air filtration/pressurization cost analysis.

*General guidance to each question, independent of answer.

Table 3. Specified in the table is the time required to use each tool, the ease of use, the type of user input, the type of guidance, the basis of evaluation of building vulnerability, and any unique features. While BVAT, BAC, and BVAMP require little time to fill the questionnaires and are based on yes/no-type answers, FEMA is much more demanding of time and user skill. It requires descriptive inputs, while CBT has drop-down menus of preset answers, which make it very user-friendly and convenient to use. While the guidance is generic for BVAT, BAC, and FEMA, and does not depend on the answers to the questions, guidance given by BVAMP and CBT is specific to the answers provided by the user. Even though BVAT, BAC, and BVAMP do not provide a metric for building vulnerability, the user does acquire a sense of it through the process of having to think through the questions. Both FEMA and CBT do provide a quantitative index of risk; however, FEMA requires that the user provide the weights for the various threats. Except for CBT, all the remaining four tools provide generic guidance. CBT provides a color-coded metric of risk broken up into separate subcategories, and also performs a cost analysis on the filtration/pressurization process.

Table 4 provides an overall classification of each tool in terms of the guidance/recommendations it provides and in terms of the vulnerability (threat) evaluation it conducts. A value of "0" means that the tool omits this feature, a value of "1" means that the tool provides a general or low-level guidance/threat evaluation, and a value of "2" means that the tool provides a guidance/threat evaluation that is still heuristic but somewhat building specific. As can be seen from this table, BVAT, BAC, and BVAMP do not provide any means of measuring building vulnerability or risk. By using these tools and answering the questions given, the building assessor may get an idea of where vulnerabilities are, but the tool itself does not provide a measure. FEMA and CBT each provides a means

Table 4. Numerical Classification

	BVAT	BAC	BVAMP	FEMA	CBT
Threat evaluation	0	0	0	2	2
Guidance	1	1	2	1	2

0 = Omitted
1 = General or low-level guidance/evaluation
2 = Heuristic guidance/evaluation, specific to the building (eliminates some possibilities)

of measuring building vulnerability, and yet both methods are heuristic. FEMA's vulnerability evaluation is highly user-specified, whereas the CBT vulnerability evaluation is automatically generated by the software once answers to all its questions are provided.

Each tool provides some type of guidance. BVAT, BAC, and FEMA simply provide general/low-level guidance that is associated with each question. BVAMP and CBT also provide general, heuristic guidance; however, they have features that make the guidance somewhat building-specific. BVAMP eliminates some of the guidance that is not relevant to a particular building depending on how the questions in the program are answered. CBT also provides guidance based on how the questions in the program are answered, making it somewhat building-specific. One note of caution, however, is that the guidance CBT provides is simply the answers that weren't chosen previously that would result in a better building vulnerability rating. The program does not provide detailed guidance in the form of descriptive text as do the other tools.

Evaluation in Terms of Guidance

In order to easily compare the guidance provided by each tool, associated summaries have been developed and can be found in Bahnfleth et al. (2008). Since the guidance from each tool deals with a wide range of topics, categories were developed to break up the guidance for easier comparison. In general, the guidance is very similar among tools with slight variations and differences that can be seen in the summaries above. BVAT, BAC, BVAMP, and FEMA all provide guidance of a general nature, depending only on the questions asked, and not on the building-specific responses. The guidance is given as a narrative in paragraph form with detailed explanations. A lot of the guidance provided by these tools is similar, suggesting that the latter ones relied on the earlier one (namely, that by FEMA). CBT is the only tool that does not provide guidance in descriptive paragraph form. CBT will be discussed further in the subsequent section. All of the tools provide guidance related to HVAC systems and airborne contaminant attacks. Some also provide guidance on related issues dealing with site and architecture. FEMA is the most comprehensive tool since it provides guidance on various aspects of the building (such as blast protection for the structural system), while the others are largely restricted to indoor airborne hazards.

EVALUATION IN TERMS OF BUILDING VULNERABILITY

Background

The five tools were also analyzed in terms of the risk evaluation capability and the guidance they provide. BAC and BVAT provide little or no evaluation of building vulnerability or risk since they are simple questionnaires with guidance provided in their appendices. The assessor who fills out these questionnaires may get some insights into specific vulnerability aspects. However, the tools themselves do not define a level or vulnerability or risk. BVAMP is basically similar to BAC and BVAT in terms of vulnerability assessment. However, BVAMP organizes the guidance in a way that could provide a preliminary vulnerability or risk evaluation. BVAMP first lists guidance measures that it recommends for all facilities. It then lists guidance that it recommends for only higher risk facilities. It also provides a couple of paragraphs describing what might make a building a higher risk facility. However, it provides no measure to indicate whether or not the building being assessed is a higher risk facility or not. That judgment is left to the assessor. Therefore, we conclude that BVAMP also does not provide a means of measuring building vulnerability.

The remaining two tools, CBT and FEMA, contain built-in features that are designed to help measure building vulnerability and risk. CBT provides a vulnerability matrix with calculated "protection levels." These protection level values are calculated based upon the answers provided by the assessor to the questionnaire. The protection levels are given as a value from 0 to 100, with 100 being the best protected. A color-coding scheme is used to make the matrix more visually appealing and easier to understand. The matrix provides eight protection assessments: prevention and mitigation for four attack scenarios, including internal, external proximate, external remote, and external warning. Once all CBT questions have been answered, the program automatically generates this color-coded matrix for the assessor to see. The program also provides a feature where the assessor can select amongst various solutions/recommendations. Once this guidance is selected, the program updates the matrix. This allows the user to see how the guidance will improve the building's vulnerability assessment.

FEMA has a color-coded matrix feature similar to CBT. However, unlike CBT, it is totally disconnected from the questionnaire. As mentioned earlier, FEMA provides two matrices: the critical functions (engineering, food service, security, etc.) matrix and the critical infrastructure (structural systems, mechanical systems, utility systems, etc.) matrix. These two matrices list these critical functions or infrastructures versus different attack scenarios (biological agent, chemical agent, radiological agent, bomb, etc). The values that must be provided to these matrices are entirely user-defined. Depending on whether or not the user is capable of defining these matrices properly, this approach may be a benefit or a drawback of this vulnerability assessment. For the FEMA matrices, the user must enter in a threat rating, an asset value, and a vulnerability rating for each critical function or critical infrastructure and for each attack scenario. These values all vary from 1–10, and the FEMA 452 document explains how one is to select these values. This selection is subjective and requires experience as well as familiarity with FEMA 452. The FEMA program then calculates a risk value (for each function/infrastructure and each attack scenario) from 1–175, with 175 being the highest risk. These values are color-coded to make the matrix more visually appealing and easier to understand.

Application of CBT to Four Buildings

The vulnerability assessment indicated that all four buildings were poor with many opportunities for improvements. The dorm building is slightly better in terms of vulnerability rating than the office-classroom building, and both urban campus buildings had better vulnerability ratings than the semi-rural campus buildings. However, the differences between the two campus results can be explained by the characteristics of the buildings evaluated. Therefore, no significant differences were found to result from having different users assess the buildings.

The dormitory has some security measures in place that a regular classroom/office building does not have, thus resulting in a better vulnerability rating than the other buildings. Reasons for the differences include, for example, having a front desk at which all occupants must present an ID prior to accessing the building. All non-residents must be signed in as guests and escorted throughout the building. Baggage check points at the ticket gates of the auditorium give it a slightly better vulnerability score. Further, it also has the benefit of HVAC zone isolation, meaning multiple, separate AHUs serve different areas of the building, which improves its vulnerability rating. In terms of the HVAC systems, all buildings are very similar in the manner in which they affect the vulnerability rating (the one exception being the auditorium's zone isolation).

The CBT software allows the user to select from among different potential solutions and simulate/visualize how that improves the vulnerability matrix. The potential solutions are simply the answers that were not selected from the drop-down menus in the vulnerability assessment questionnaire. Therefore, CBT does not provide detailed recommendations based on actual analysis. However, an experienced and knowledgeable user can deduce what the potential solutions imply in terms of guidance and recommendations. As mentioned earlier, the potential solutions are classified in terms of cost and technical maturity. The final summary page of the program assembles the original matrix (with separate categories for prevention/mitigation and type of threat [internal, external proximate, external remote and external warning]), the potential solutions that were selected, and the resulting final matrix.

Several of the potential solutions are somewhat vague and arbitrary. For example, the protection level metric (or number) for "external warning—prevention" always had a score of 0 for both buildings in their existing condition. The only potential solution offered in this category is "chem-bio training for security personnel," which had two levels: "some training" and "full training," which pushed the protection level to 50 and 100 (the maximum attainable), respectively. Since the type and detail of training is not specified, nor has such a training been developed to date, the increase in protection level of such training is questionable.

Selection of potential solution automatically raises the vulnerability rating of a building (i.e., lowers its vulnerability) after implementation. One shortcoming of this feature is that the CBT assumes the solution to apply to all buildings, which may be true in a general sense, but may be invalid for specific buildings. For example, it has been shown that central HVAC shutdown as a security enhancement can have a negative impact on a building's exposure during a CB attack if done too late, which may be a matter of only a few minutes after a release occurs (Persily et al. 2007). Having the vulnerability assessment program suggest to a user that their proposed solutions will provide some level of protection without simulating how it functions in the actual building can create drastically misleading results.

Application of the FEMA Tool

It was our original intention to evaluate the reliability and usefulness of the FEMA threat matrices and hopefully make a comparison to the risk evaluation features of CBT. A general comparison between the two tools in terms of risk evaluation can be made by simply understanding how each tool works. However, a specific comparison between the outputs of the two tools for the buildings evaluated in this study could not be conducted. On trying to do so, several difficulties were encountered that did not allow us to complete the threat matrices.

First, as mentioned previously, the FEMA threat matrices are highly user-defined. The risk values provided are not connected to the questionnaire or to the guidance. In CBT, the protection levels are calculated automatically by answering each question. With FEMA, however, the risk evaluation is a separate feature. Filling out the matrices is a complex process with a lot of ambiguities. Determining the threat rating, vulnerability value, and asset value for each critical function/infrastructure and for each attack scenario requires extensive knowledge of the building being assessed and the scales discussed in FEMA 452. Experience with such evaluations would also be helpful. The asset value, threat rating, and vulnerability rating are all on scales of 1–10. The process of choosing these values for each critical function/infrastructure and for each attack scenario is highly subjective. The resulting risk values from one user could vary significantly as compared to the values from another user evaluating the same building. This is totally different compared to the CBT tool where the generated protection levels were determined by the developers of the software rather than the user.

FEMA also provides guidance that exceeds the scope of this study. For example, many of the thirteen FEMA assessment categories involve building security/vulnerability issues that have nothing to do with airborne contaminant attacks. Likewise, the threat evaluation matrices involve different types of threats or attack scenarios, such as explosive attacks, nuclear attacks, cyber terrorism, etc. Altogether, the matrices give 12 different threat types with the option for the user to add more. Of those 12, only 3 apply to airborne contaminant attacks. The only attack scenarios in the scope of this study are chemical, biological, and radiological attacks, which are airborne attacks and deal with building indoor air quality. These matrices also include functions and infrastructures that are outside the scope of this study. If the FEMA risk evaluation tool were to be applied to the buildings in this study, only a small portion (the portion that applies) of the matrices would be filled out.

Finally, if a small portion of these matrices were to be filled out there would be nothing to compare them to, i.e., there is no basis of comparison. How do these "risk values" that are generated by FEMA (on a scale of 1–175) compare to the "protection levels" that are generated by CBT (on a scale of 1–100)? There seems to be no logical means of comparison between the results of the two tools. There is no way to conclude that one tool has determined a building to be at a higher risk/lower risk/same risk as predicted by the other tool. Therefore, attempting to fill out these FEMA matrices would be time consuming, and the results would be arbitrary with no basis for comparison.

Comparison of CBT and FEMA Risk Evaluations

The FEMA risk evaluation is broken down by different types of threats, whereas CBT is broken down by the source of the threat (internal vs. external). As mentioned previously, FEMA deals with many different types of attacks. CBT, however, deals only with airborne contaminant attacks.

FEMA calculates a risk value using the following formula:

$$\text{risk} = \text{asset value} \times \text{threat rating} \times \text{vulnerability rating}$$

CBT calculates only a vulnerability rating in the form of a "protection level," which is inversely proportional to a vulnerability rating (higher protection, lower vulnerability).

These risk/vulnerability evaluations are only focused on physical systems. This is especially true of CBT, which only calculates a vulnerability rating measure. FEMA takes an extra step and calculates risk depending on asset values and threat ratings. These two factors take into account the value of building assets and the increase in threat due to different aspects such as building occupancy. As discussed in Part 1 of this paper (Reddy et al. 2011), the Building Security Council's Building Security Rating System (BSC 2008) is a subsequent improvement because it determines risk (in the form of security rating) based on many primary and secondary factors. These factors include additional factors beyond physical building issues. Threat history, economic importance, historical importance, national prominence, and number and type of occupants, as a few examples, are all taken into account when determining the building's risk from an attack. The ASHRAE risk management guidance document (ASHRAE 2009) also takes factors such as these into account.

NEEDS FOR FUTURE RESEARCH AND DEVELOPMENT

The investigation described above lead us to identify the following features and capabilities of an ideal assessment tool for indoor airborne risk. These are listed below:

1. Tools should be easy to use and intuitive. Developing interactive software programs is highly recommended. Ways of combining the information storage and database capabilities of FEMA with the interactive features of CBT should be explored.
2. Tools should use questionnaires that allow answers specific to the building to be captured in the interactive tools. These questionnaires should be designed to permit the user to make a nuanced response rather than try to make all of them into yes/no answers (like BVAMP). A drop-down menu of possibilities is one appealing approach. Along with drop-down menus, there should be space for the user to enter in other observations or elaborate on the answer. FEMA's database capabilities allows for this.
3. All tools should explicitly compute building risk in some way by including the three different aspects of threat identification, probability of occurrence, and consequence of event. CBT does not do this, while FEMA does. One suggestion is to have a common method (mathematical formula) for calculating risk so that the numerical results from one tool can be compared to the results from another. Currently, FEMA and CBT cannot be compared in this way. This would, obviously, require communication and agreement among the various organizations developing assessment tools.
4. Building risk assessments should take into account more than just physical building features. Political, religious, economic, historical, and occupancy issues, for example, should also be considered when determining risk. How one does this without assigning arbitrary or subjective weighting values to each issue is to be explored, as should additional solutions to this problem.
5. Tools should have the capability to be applied to a specific building. All building risk assessments are general in nature, and largely heuristic. Though this approach is the logical one at the outset, it is recommended that assessments become more quantitative and building-specific and use some broad characteristics that can be measured or estimated (like air changes per hour,

time constant, etc.). Simple two-zone models that allow analytical solutions and can provide additional insights should be investigated.

6. Risk assessment tools should have the option to be integrated with simulation programs such as CONTAM (Walton and Dols 2008) and modeling programs so that guidance can truly be building-specific and not just general.
7. Tools should compute cost of consequences (loss of lives, clean-up, lost work time, etc.) to produce an all cost metric (perhaps life-cycle cost) to aid in decision making.
8. Tools should only provide guidance specific to the building based on the answers provided in the questionnaire portion of the tool (this is done by CBT but not by the others). Even if the guidance is generic in nature, it is better to only list those applicable to the specific building rather than list all types of guidance applicable.
9. Tools should integrate the strong features of CBT and FEMA into one tool. For example, the database features of FEMA, the easy-to-use and automatic vulnerability calculation of CBT, the guidance sorting of BVAMP, etc.
10. All tools should have some cost/economic analysis features. These features should be integrated with the guidance provided by the tool. The user should be able to get a sense of how implementing the suggested guidance/potential solutions will affect the building from a cost perspective.
11. Tools should integrate more realistic first, operating, and maintenance costs figures for potential solutions.
12. Tools should provide more detailed guidance, including common methods and procedures for implementing the various recommendations. More detailed procedures on what to do for different attack scenarios should be included. Even though attacks are building-specific, tools can provide general guidelines and a list of “do’s” and “don’ts.” Attack scenarios include chemical agent vs. biological agent and indoor release vs. outdoor release, for example.
13. Tools should have a feature similar to CBT where one can visualize how implementing various recommendations improve the buildings risk/vulnerability ratings. The guidance features and risk evaluation features of all tools should be integrated rather than separate.

SUMMARY

This paper is the second of a two-paper sequence reporting on the results of a study undertaken to: (1) review and classify analysis methods, tools and simulation programs that allow analytical prediction of airborne chemical and biological dispersal and transport dynamics in indoor environments subject to different risk scenarios, and (2) identify and describe tools that allow the practical evaluation of vulnerability of building occupants to indoor air threats, and determine the pragmatic and useful effect when specific countermeasures are implemented. While scope (1) was addressed in the companion paper (Reddy et al. 2011), this paper dealt with scope (2). After an in-depth description of the five tools that were identified, two of them (since the other three tools lacked the necessary specificity to do so) were applied to four carefully selected buildings in two different campuses, and the results of our analysis were documented. Suggestions for future modifications to these tools in order to make them more user-friendly while enhancing their capabilities have also been proposed.

ACKNOWLEDGMENTS

This work was supported by the National Center for Energy Management and Building Technologies (NCEMBT) under cooperative agreement DE-FC26-03GO13072 for the U.S. Department of Energy. The authors would like to thank NCEMBT Chief Technology Officer Davor Novosol for his support and guidance throughout the study. The comments and input of James Freihaut and Greg Dobbs are also acknowledged.

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