April 22, 1999

EPA-SAB-IHEC-ADV-99-007

Honorable Carol M. Browner
Administrator
U.S. Environmental Protection Agency
401 M Street, SW
Washington, DC 20460

Subject: SAB Advisory on Defining the Trade-offs Between Instituting Indoor Air Quality and Energy Controls

Dear Ms. Browner:

The Integrated Human Exposure Committee (IHEC) of EPA's Science Advisory Board, supplemented by an economist (a liaison from the SAB Environmental Economics Advisory Committee), reviewed the draft EPA project reports on Energy Costs and Indoor Air Quality Performance of Ventilation Systems and Controls. This review was conducted during a public meeting which took place in Washington, DC. The reports summarize the results of an EPA modeling effort by the Office of Air and Radiation, Office of Radiation and Indoor Air (ORIA), Indoor Environments Division. The purpose of this project was to assess the compatibilities and trade-offs between energy and indoor air quality objectives in the design and operation of heating, ventilation, and air-conditioning (HVAC) systems in commercial buildings (EPA 1999a-g). This modeling effort was also designed to shed light on potential strategies which can simultaneously achieve superior performance on energy and indoor air quality. ORIA chose a computer modeling approach in order to investigate multiple variations of building configurations and climate variations at a scale that would not otherwise be possible with field study investigations.

ORIA was particularly concerned about this data void because the building industry, in general, has assumed that providing ventilation in order to have good indoor air quality is incompatible with the goal of reducing energy costs. Based upon this computer modeling project, ORIA concluded that "protecting or improving indoor environmental quality during energy efficiency projects need not hamper energy reduction goals." Consequently, in its draft reports, the EPA concludes that indoor environmental quality appears to be compatible with energy efficiency goals when energy saving measures and retrofits are applied wisely. ORIA plans to utilize the data from this modeling effort to develop public policies and strategies that are directed toward improvements in building performance as it relates to public health, productivity, and the conservation of energy resources.

The Committee was charged to respond to the following Charge questions:

a) Is this project adequately defining the trade-offs between instituting indoor air quality and energy controls to the stakeholders?;

b) Is the interpretation of the results reasonable and do the conclusions follow logically from the results?;

c) What additional advice does the Committee have regarding the adequacy of the analyses?; and

d) Does the Committee have advice on how the results can best be disseminated to the appropriate stakeholders?

Overall, the Committee found the Energy Cost and Indoor Air Quality Performance of Ventilation Systems and Controls Project to be well-executed and clearly presented. The Committee was particularly impressed with the technical components of the methodology. The Committee also found that, in general, the findings of the report were supported by the modeling results and that, in general, the analyses were adequate for understanding some differences in the costs associated with having good indoor air quality amongst different ventilation systems. The major contribution of this modeling effort is that the results suggests that the tradeoffs are not very large, rather than that they do not exist. Also, it is important to note that the major findings relate to modeling HVAC systems and their relationship to IAQ, rather than to other energy conservation measures. The objective and some of the findings (which are presented below in items a through f) were not clearly presented. IHEC strongly recommends that some of the results be presented more clearly so that they do not imply that tradeoffs do not exist. Consequently, IHEC found the ORIA reports to be ready for dissemination and broader discussion as long as the Agency further clarifies the limitations and caveats of the model and addresses the Committee's immediate concerns which are identified below.

a) The Agency should state the objective of the study more clearly in its introductory report and should consider breaking down the objective into sub-objectives that represent tasks in order to enable a clearer appreciation of the utility of this project.

b) The Agency should clarify whether or not the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) standard is being used to measure indoor air quality (IAQ) performance (as an indicator of good indoor air quality) or to actually determine IAQ. ASHRAE's latest ventilation standard is 20 cubic feet per minute of outside air per occupant (ASHRAE, 1989). The ASHRAE standard for quantity of outdoor air apparently is intended to be sufficient to handle a wide range of internally-generated air pollution. If the ASHRAE standard is being used to determine IAQ, the Agency should address the limitations of relying solely on ventilation to achieve good IAQ.

c) The EPA should further clarify the limitations and caveats of the model. For example, it should also be stated up-front that this model does not address management measures for improving indoor air quality such as HVAC maintenance and the indoor use of cleaners and pesticides containing fewer or less volatile chemicals.

d) The Agency should revisit the statement on page 3 of ORIA's Executive Summary that "despite these limitations, it is believed that the modeling analysis in this study is sufficiently representative of actual conditions in both new and existing buildings" given a fundamental limitation that the model assumed that all equipment functioned as it was intended (EPA, 1999a).

e) The Agency should provide supporting data for the key finding that appears on page 8 of the Executive Report. That key finding addresses the effects of energy recovery technologies on humidity control, energy cost and sizing problems (EPA, 1999a).

f) Finally, the Agency should explain more clearly its conclusion that "protecting or improving indoor environmental quality during energy efficiency projects need not hamper energy reduction goals." In particular, the four findings cited to support that statement should be described more clearly.

Currently, the analysis is most valuable for demonstrating the basic principle that improved indoor air quality does not necessarily carry a major penalty in terms of energy conservation. The Committee found that additional work in several areas would strengthen the analysis when it is used to support specific policies. Specifically, the IHEC recommends that: a) the EPA work with DOE to further validate the DOE-2 model; b) the Agency clarify the significance of applying the ASHRAE standard and state whether or not the Agency is assuming that compliance with the ASHRAE standard implies that the indoor air quality is good for a given building and; c) the EPA further explain the cost of achieving improvements in IAQ by adjustments in the HVAC system, the cost associated with poor indoor air quality, and the benefits of improving indoor air quality through reduced occupant illness. The IHEC also offered the following suggestions to be considered as ongoing research directions for future analyses:

a) The model should undergo a higher level of validation before the analysis is used to develop specific policies (e.g., use the Building Assessment and Survey Evaluation (BASE) buildings, to the extent feasible, and determine if the modeled results are the same as those measured by BASE, a cross-sectional multi-year study designed to define key characteristics of IAQ in 100 public and commercial buildings (SAB, 1999));

b) The Agency should consider the limitations of the ASHRAE standard. For example, the standard may not be adequate when outdoor air quality is poor, especially for $PM_{2.5}$, PM_{10}, and ozone. By defining parameters such as these more clearly, there is less opportunity for the public to have unreasonable expectations from the results of the modeling in actual buildings;

c) The EPA should conduct a more detailed economic evaluation of total costs including capital costs, the costs of occupant illness associated with changes in indoor air quality, and the cost of using filters to clean ventilation air contaminated with particulates. The cost of using filters includes the cost of the filters themselves, installation costs, and energy cost of moving air through the filtration media; and

d) The EPA should work with DOE to further validate the model.

The Committee appreciates the opportunity to provide advice to the Agency on the Energy Cost and Indoor Air Quality (IAQ) Performance Of Ventilation Systems and Controls Project. Overall, the Committee was very enthusiastic about this information on energy cost and IAQ performance of ventilation systems and controls given the previous lack of information about the relationship between energy use and IAQ performance of ventilation systems and the Agency's preliminary finding that energy cost and IAQ performance appear to be compatible when energy saving measures and retrofits are applied wisely. The Committee looks forward to receiving a written response from the Assistant Administrator for the Office of Air and Radiation.

Sincerely,

/signed/
Dr. Joan M. Daisey, Chair
Science Advisory Board

/signed/
Dr. Henry A. Anderson, Chair
Integrated Human Exposure Committee
Science Advisory Board

IHEC ADVISORY ON ENERGY COST AND IAQ PERFORMANCE OF VENTILATION SYSTEMS AND CONTROLS

1. Introduction

The Integrated Human Exposure Committee (IHEC) of EPA's Science Advisory Board, supplemented by an economics consultant, met on March 10, 1999 to review the draft project reports on Energy Costs and IAQ Performance of Ventilation Systems and Controls in a public meeting in Washington, DC. This project was designed by the EPA Office of Air and Radiation, Office of Radiation and Indoor Air, Indoor Environments Division. The project reports summarize the results of an EPA modeling effort whose purpose was to assess the compatibilities and trade-offs between energy and indoor air quality objectives in the design and operation of HVAC systems in commercial buildings. This modeling effort was also designed to shed light on potential strategies which can simultaneously achieve superior performance on the energy and indoor air quality objectives. The Agency chose a computer modeling approach in order to investigate multiple variations of building configurations and climate variations at a scale that would not otherwise be possible with field study investigations.

In designing this energy cost and IAQ performance of ventilation systems and controls modeling effort, the Office of Radiation and Indoor Air (ORIA) hoped to contribute to the body of new data needed by professionals and practitioners who design and operate ventilation systems as they attempt to reduce costs and save energy without sacrificing thermal comfort or outdoor air flow performance. ORIA is concerned about helping to fill this data void because the building industry has generally assumed that providing ventilation in order to have good indoor air quality is incompatible with the goal of reducing energy cost since energy is required to run ventilation systems:

DOE-2 was not originally designed to study the trade-offs between instituting good indoor air quality and energy costs. The DOE-2 model was originally designed to provide a means of investigating, in detail, the behavior of the many individual building components that affect energy use. Therefore, ORIA refined and adapted the DOE-2 building energy analysis computer program to resolve problems in the areas of: infiltration, HVAC equipment sizing, outdoor air controls, control strategies, exhaust systems, and heat recovery systems:

a) *Infiltration* - Infiltration is the uncontrolled movement of outdoor air into a building through means other than the ventilation system (i.e., through cracks and other uncontrolled openings in the envelope of the building). The DOE-2 infiltration model was modified to calculate the infiltration rate for a given zone based on wind direction and speed.

b) *HVAC equipment sizing* - Since the DOE-2 does not reliably model undersized or inefficient HVAC equipment which may be found in some older buildings, ORIA did not use the auto sizing algorithm in DOE-2. The Agency identified two problems related to HVAC equipment size. First, the Agency found that the energy consumed by under-sized systems was underestimated. Second, the Agency found that the auto-sizing algorithm often provides inadequate supply air to core zones that are served by VAV system. Therefore, the EPA made a concerted effort to ensure that the HVAC equipment was adequately sized for all runs of the model.

c) *Outdoor air controls* - Two DOE-2 modeling issues related to outdoor air flow control were identified by the EPA. Consequently, another DOE-2 function was created because the original DOE-2 does not have a fixed position outdoor air damper control for VAV systems and the default settings for VAV box minimum settings and for night time operation create problems (The definition for VAV is provided in Appendix B). In this function, the design outdoor air flow is decreased in proportion to the reduction in the fan flow rate at any part-load condition, varying the outdoor air flow rate continually through each hour, day, and season. Also, the minimum VAV box setting for all runs was set to 30 percent.

d) *Control strategies*
Another problem identified was the minimal guidance provided to model control strategies. Most control strategies have the following three operating modes each day: a) occupied or day mode; b) unoccupied or night mode; and c) morning startup mode. ORIA identified the most commonly used control strategies for each type of equipment modeled and carefully tested and refined detailed input models prior to generation of the first results of the study.

e) *Exhaust systems* - An exhaust system removes the air from the building and returns it to the outside. It was also found the that DOE-2 is very limited in its ability to model operational strategies for exhaust systems because it cannot schedule on/off mode. ORIA wrote a DOE-2 “function” and inserted it into the DOE-2 input file to shut-off the exhaust and the outdoor air during hours when the building was unoccupied. A separate function was required for each type of outdoor air damper control strategy.

f) *Heat recovery systems* - A heat recovery system can significantly reduce the energy associated with heating or cooling large amount of outdoor air. ORIA identified problems associated with DOE-2's ability to model heat recovery because DOE-2, as originally designed, cannot model both latent (cooling season) and sensible (heating season) heat recovery in the same simulation. Consequently, EPA combined separate runs for summer and winter to approximate a single simulation.

An office building, education building and an assembly building were modeled in this project. The office building database consisted of output from over 600 DOE-2 simulations that included fourteen office building variations, three climate regions, six HVAC system/outdoor air control combinations, and two outdoor air flow settings. The education and assembly building database consisted of output from over 100 DOE-2 simulations that included three climate regions, four ventilation configurations, and two outdoor air flow settings.

ORIA found that protecting or improving indoor environmental quality during energy efficiency projects need not hamper energy reduction goals and consequently ORIA concluded that indoor environmental quality appears to be compatible with energy efficiency goals when energy saving measures and retrofits are applied wisely. The Office of Radiation and Indoor Air plans to utilize the data from this modeling effort to develop public policies and strategies that are directed toward improvements in building performance as it relates to public health, productivity, and the conservation of energy resources.

Despite the modifications to the DOE-2 computer model, three fundamental limitations remained. Those limitations were recognized by the Agency and explained in ORIA's Executive Report (EPA, 1999a). The analysis is ultimately constrained by the inability of the model to accurately reflect real world conditions. In addition, the building parameters used to capture the relevant variations in the building stock and their ventilation systems cannot be considered fully representative due to the exceptionally large variety of building features and ventilation system features that characterize the building stock. Finally, the modeling assumed that all equipment functioned as it was intended to function. This is often not the case since poor design, poor operations, and malfunctioning equipment are not uncommon in existing buildings.

2. General Comments

2.1 Charge to the Panel

The Committee was charged to respond to the following Charge questions:

a) Is this project adequately defining the trade-offs between instituting indoor air quality and energy controls to the stakeholders?;

b) Is the interpretation of the results reasonable and do the conclusions follow logically from the results?;

c) What additional advice does the Committee have regarding the adequacy of the analyses?; and

d) Does the Committee have advice on how the results can best be disseminated to the appropriate stakeholders?

2.2 General Issues

In general, the Committee found the Energy Cost and Indoor Air Quality Performance of Ventilation Systems and Controls Project to be well-executed and clearly presented. The Committee was particularly impressed with the technical components of the methodology. The Committee also found that, in general, the findings of the report were supported by the modeling results and that, in general, the analyses were adequate for understanding some differences in the costs associated with having good indoor air quality amongst different ventilation systems. Consequently, IHEC found the ORIA reports to be ready for dissemination and broader discussion as long as the Agency further clarifies the limitations and caveats of the model and addresses the Committee's immediate concerns, as identified in the next section. The Committee also provides suggestions for ongoing research directions for future analyses.

3. Comments by Charge Question

3.1 Defining the Trade-Offs Between Instituting Indoor Air Quality and Energy Controls

Is this project adequately defining the trade-offs between instituting indoor air quality and energy controls to the stakeholders?

Overall, the Committee found this project to be well-executed and clearly presented. The technical components of the methodology were particularly impressive. The Energy Cost and IAQ Performance of Ventilation Systems project demonstrates that the conflict between indoor air quality and energy conservation is much smaller than it is typically perceived to be. Consequently, this project has very practical implications. However, prior to the distribution of the project reports, the Committee strongly recommends that the Agency state the objective of the study more clearly in its Executive Summary and provide additional clarification on the limitations and caveats of the project as explained in more detail below. These IHEC recommendations will help to increase the utility of the project reports in defining the trade-offs between instituting indoor air quality and energy controls to the stakeholders.

The intent of the study appears to be to examine the degree of conflict between achieving improved indoor air quality and reducing energy use and costs, where indoor air quality appears to be defined as achievement of the ASHRAE standards. Making that objective clearer will improve the definition of what the study is, as well as what it is not. Currently, the analysis is most valuable for demonstrating the basic principle that improved indoor air quality does not carry a major penalty in terms of energy conservation. The Committee found that additional work in several areas would strengthen the analysis when it is used to support specific policies.

The limitations and caveats should be explained more clearly up-front to reduce the likelihood that the study will result in unreasonable expectations from the public regarding the compatibility between indoor air quality costs and energy costs. For example, it should be stated up-front that this model does not address management measures for improving indoor air quality, such as HVAC maintenance, and the indoor use cleaners and pesticides containing fewer or less volatile chemicals.

For several reasons (to be discussed below), the Committee found that additional work in several areas would strengthen the analysis when it is used to support specific policies. For instance, the modeling effort probably is insufficient to recommend a particular kind of HVAC system for any particular building. These concerns with the analysis, as noted before, are not intended as criticism of the current work. The Committee provides the following suggestions regarding: a) the validation of the DOE-2 model; b) the sufficiency of the ASHRAE standard; c) the modeling of energy costs; and d) additional parameters to be considered as ongoing research directions for future analyses.

a) *Model Validation* - The Committee would like to see further demonstration that the model is a reasonable representation of the reality that it is trying to portray. Clearly, this effort and the conclusion rendered represent valuable insights into the dynamics of the process. The level of evaluation or validation that this particular modified DOE-2 model has undergone was unclear. What level of validation is extant or might be anticipated to bolster the credibility of this analysis? Given EPA's conclusions and the potential policy impact of the results, the IHEC recommends that the model undergo a higher level of model validation and urges the EPA to work with DOE in that effort.

One suggestion to assist the validation is the identification and simultaneous testing of "twin buildings," i.e., buildings of essentially identical construction at the same physical location such as similar or almost identical office buildings in a complex. The Agency could repeatedly measure energy loads in real time at various ventilation settings under the same weather conditions. The Committee also recommends that the Agency model the BASE buildings, to the extent feasible, and determine if the modeled results are the same as those measured by BASE. The IHEC conducted an advisory on the analyses of the BASE data on the day before its advisory on energy cost and IAQ performance of ventilation systems and controls (SAB 1999).

b) *The ASHRAE Standard* - The IHEC strongly recommends that the Agency clarify whether or not the ASHRAE standard is being used to measure IAQ performance or IAQ. ASHRAE's latest ventilation standard is 20 cubic feet per minute of outside air per occupant (ASHRAE, 1989). The ASHRAE standard for quantity of outdoor air apparently is intended to be sufficient to handle a wide range of internally-generated air pollution. However, it was designed largely based on odor perception. This project seems to imply that additional outdoor air is equivalent to better indoor air quality. The Committee was concerned about this implication because there are limitations in relying on ventilation alone to achieve good indoor air quality For example, two identical buildings with identical ventilation systems may have very different indoor air quality characteristics, based on internal sources and on the quality of the outdoor air. IHEC was also concerned that the ASHRAE standard may not be adequate when outdoor air quality is poor, especially for $PM_{2.5}$, PM_{10}, and ozone. (ASHRAE, 1989)

In regions of the country that fail to meet the National Ambient Air Quality Standards (NAAQS) for criteria pollutants such as particles or ozone, increasing the amount of outdoor air beyond a certain point, especially through the use of economizers, has the potential of actually degrading the indoor air quality. (Economizers are a commonly used energy efficiency measure in continuous volume and variable air volume ventilation systems. Economizers can significantly reduce the cooling energy requirements while increasing the outdoor air flow rates of a ventilation system.) This can be avoided by cleaning the ventilation air (at least partially) through the use of appropriate filters, including particulate filters, or charcoal or chemically treated filters for ozone. However, the cost of such filters (the cost of the filters themselves, installation costs, and energy cost of moving air through the filtration media) must be considered in fully "defining the trade-offs of instituting indoor air quality and energy controls to the stakeholders."

To be more specific, if a building in a densely populated urban area is using economizers, it is prudent to use HVAC filters with at least an 85% ASHRAE dust spot rating. If a building is not using economizers, filters with an ASHRAE dust spot rating of 30% or less may be sufficient. The former will have a larger energy cost (larger average delta P (pressure drop) across the filters during service life) than the latter. The energy cost of using filters with larger average pressure drops does not appear to be included in the modeling. Although at this point it is not practical to include this factor in the simulations, the Agency should consider mentioning, in the final presentation, the possible limitation associated with not including the cost of such filters when "defining the trade-offs of instituting indoor air quality and energy controls to the stakeholders." (Note: Within the last four years, so-called "high efficiency/low pressure drop" filters have become available. Some of the 85% or 95% filters in this category have pressure drops comparable to 30% filters. Hence, there is less of an energy penalty with these filters.

However, those filters do have a higher initial cost than traditional 85% or 95% filters).

In summary, even if it is true that the ASHRAE standard adequately controls indoor air quality for buildings with varying internal sources of pollutants, the modeling effort does not address the effects of variations in outdoor air quality. Future research should incorporate the effects of differing outdoor air quality levels.

The studies mention that the ASHRAE standard is typically violated in many parts of the buildings in many of the scenarios examined. In those cases, the analyses presented are not indications of the energy cost of achieving the ASHRAE standard. The Committee recommends that the Agency improves the presentation of material in order to more clearly demonstrate the relationship between energy use and the level of indoor air quality. This, in turn, would clarify potential tradeoffs. For instance, it would be useful to graph, for different technologies and settings, the percent of outdoor air and the energy consumption for the part of the building with poorest air quality. If that relationship is upward-sloping, there is a tradeoff; the degree of slope would indicate the degree of the tradeoff.

c) *Costs* - There are two costs of concern that should be addressed when defining the tradeoffs between instituting indoor air quality and energy controls. The first cost is that of achieving improvements in IAQ by adjustments in the HVAC systems. The other cost is that associated with poor indoor air quality and are the benefits of improving indoor air quality through reduced occupant illness.

Since DOE-2 was designed to focus on operating costs of energy, developing rough estimates of the costs of not improving indoor air quality is likely to be a difficult effort. However, estimates of costs associated with poor indoor air quality could greatly improve understanding of the nature of the balancing between indoor air quality and energy reduction. Also, such data would be useful in justifying public policy, especially given the non-regulatory nature surrounding indoor air quality issues. Examples of measures for improved occupant illness could include epidemiological links between IAQ and health, sick days or other measures of worker well being such as worker absenteeism or worker productivity. To the extent possible, those analyses should be conducted on a marginal basis - that is, rather than measuring the total costs due to worker illness, the focus of those studies should be the change in worker illness (and its associated value) for a specified change in indoor air quality. However, there are uncertainties associated with these measures of worker well being. For example, there is uncertainty around the epidemiological links between IAQ and health, and uncertainty associated with the costs associated with health effects associated with IAQ. Therefore, the Committee recommends that the EPA state the estimate on the billions of dollars that can be saved by good indoor air quality by using a range instead of a point estimate and that the Agency present the uncertainty embodied in these estimates and the resulting "stochastic clouds" associated with these estimates for the consideration of the policy makers.

3.2 Interpretation of the Results

Is the interpretation of the results reasonable and do the conclusions follow logically from the results?

Overall, the IHEC found the results to be reasonable and that the conclusions follow logically from the results since the key findings of this report, in general, are supported by the modeling results. However, the Committee was concerned that three of the 15 key findings were not adequately supported by data and urges the Agency to either provide the justification for the following conclusions or eliminate them if adequate supporting data do not exist:

a) On page 8 of the Executive Summary report, the Agency states *"...that literature suggests that both latent and sensible energy recovery systems can significantly reduce or eliminate the associated problems of controlling thermal comfort, reducing energy costs, and downsizing equipment needs ..."* However, in this report, no systematic literature review on energy recovery technologies can be found to support this statement.

b) The last key findings states that "protecting or improving indoor environmental quality during energy efficiency projects need not hamper energy reduction goals." In citing this findings, the Agency presents the following results which need to be explained more clearly: 1) "Energy efficiency measures, properly adjusted to either enhance or not degrade indoor environmental quality, when taken with measures to meet the outdoor air requirements of ASHRAE Standard 62-1989, have the potential to cut energy by 35% - 55% in typical buildings;" 2) "Operational measures compatible with indoor environmental quality can save 10%-20%, while retrofit measures can save 35%-45% of total energy costs"; and 3) "Avoiding operational measures that degrade indoor environmental quality would forego reductions of only 3%-5% in office buildings; and 7%-10% in education buildings." In presenting the above-cited findings more clearly, the Agency should clarify that there are trade-offs for instituting good indoor air quality, even though they do not appear to be large.

c) Supporting data were not provided for the conclusion that "Despite these limitations, it is believed that the modeling analysis in this study is sufficiently

> representative of actual conditions in both new and existing buildings . . . "? The report recognizes that the analysis of this project has several limitations. Therefore, the project is constrained by the ability of the model to accurately reflect real world condition. The modeling assumed that all equipment functioned as it was intended, while it is not uncommon to find poor design, poor operations and malfunctioning equipment in existing buildings. Building parameters used in the model cannot be considered fully representative of the large variety building and ventilation features.

DOE-2 is considered one of the fully featured and sophisticated computer models for building energy analysis. Yet, the best modeling tool still has some inherent weaknesses. . Modifications were made to overcome problems in several areas: infiltration, HVAC equipment sizing, outdoor air controls, control strategies, exhaust systems, and heat recovery systems. However, it was unclear whether or not the modified DOE-2 has been validated against empirical data. Therefore, as stated in the response to Charge Question 1, the Committee would like to see, as a future research effort, further demonstration that the model is a reasonable representation of the reality that is trying to portray. Also, the Agency should include, in the project reports, any data on validation of the model.

The IHEC identified a few “inconsistencies” in the report. During the meeting, the Agency explained that the “inconsistencies” were typographical errors. The Committee’s editorial comments on the draft reports are provided in Appendix C.

3.3 Additional Advice Regarding the Adequacy of the Analyses

What additional advice does the Committee have regarding the adequacy of the analyses?

In general, the analyses were very appropriate and well-conceived, and the results were well-documented. Also, in general, the analyses were adequate for exploring specific issues without answering all. They also provided adequate understanding of some differences between systems, costs associated with having good air quality, and cost savings with changes in total indoor systems. The IHEC strongly recommends that the Agency provide estimates of the uncertainties embodied in the "stochastic cloud" of IAQ & energy costs. The IHEC also recommends that the Agency consider displaying the results in the form of a matrix in which the ventilation systems (with parameters as sub-sets) would be on one axis and the criteria (energy consumption, cost, Indoor Environmental Quality (IEQ), or IAQ) would be on the other axis.

In particular, the inclusion of ASHRAE ventilation was very useful. Also, the consideration of potential for poor indoor air quality was very worthwhile, especially as it pinpointed the problem with one of the optional systems (VAV [FOAF])(See Appendix B). Evaluation of energy measures (and costs) compatible with IEQ, and those that may degrade IEQ, was also a very useful (and necessary) exercise. The energy-cost analyses will be very useful to many stakeholders. Evaluation of potential staged modifications of systems also was very worthwhile, especially with the energy cost changes that related to such modifications. However, the Committee recommends that the Agency expand, in the Executive Summary, on the discussion about the problems and costs associated with the use of undersized equipment.

Some of the black-box aspects of the modeling does not allow one to evaluate all of the differences (or lack of differences) in all the comparisons. For instance, the Committee was surprised that the results for Washington, DC and Miami in summer were quite different. The Committee expected larger costs than those reported. The Agency found an increase in energy costs associated with heating when increasing outdoor air from 5 to 20 cfm/person and only a 12-13% increase for cooling in Washington, DC and Minnesota office buildings. Another example is that the data did not allow the reader to determine whether or not the large increases in the cost of heating with increased densities in the Education Building and the Auditorium were due solely to humidification requirements.

The choice of systems for comparative purposes was quite good, even though it was not complete. The Agency should, for future analyses, consider including: a) more outdoor air (OA) flow bins; b) more ranges of temperature; c) more climates (IHEC recommends that future analyses include at least two additional climates, a Denver-like climate due to the high altitude and a Phoenix-type climate); d) the use of filtering ventilation for IAQ (and the trade-offs); and e) the effects of different building materials. Future work could also include: a) validating the model using Building Assessment Survey and Evaluation (BASE) data; b) conducing research on the relationship between the ASHRAE standard (amount of outdoor air) and actual indoor air quality, and/or on the relationship between the amount of outdoor air and human health. Is the ASHRAE target really going to be effective, if achieved? Or will we need, over time, to move toward more pollutant-specific standards?; c) using $PM_{2.5}$ & VOCs as tracer gases to estimate infiltration in BASE buildings, and use these infiltration estimates in these models; d) including other technological options for relative humidity control (e.g., heat coils, different desiccator systems; and e) addressing, in more detail, the cost of retrofitting.

3.4 Advice on the Dissemination of the Results to the Stakeholders

Does the Committee have advice on how the results can best be disseminated to the appropriate stakeholders?

The Committee has concerns about the policy implications of this question, especially given that the IHEC does not represent a group of stakeholders. Therefore, the Committee recommends that the Agency seek advice on the dissemination of the results from the stakeholders. Other federal agencies, environmental advocacy organizations, the building industry, energy conservation organizations, and organizations focused on reducing sick building syndrome are some potential stakeholders that were identified by the IHEC. However, this list is not meant to be comprehensive. The Committee recommends that the Agency define, in its report, the audience for its results. This will, in turn, help the Agency to identify the stakeholders. In addition, by identifying its audience, the Agency may find that it must modify the presentation of the material so that the project reports adequately define the tradeoffs between indoor air quality and energy costs to the stakeholders. The Committee also recommends that the Agency hold workshops on energy cost and indoor air quality performance of ventilation systems and controls as another method for communicating with stakeholders.

U.S. Environmental Protection Agency
Science Advisory Board
Integrated Human Exposure Committee
IHEC Energy Cost and IAQ Performance of Ventilation Systems and Control Advisory Panel

Environmental Economics Advisory Committee

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NOTICE

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REFERENCES

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APPENDIX A - ACRONYMS AND ABBREVIATIONS

ASHRAE	-	American Society of Heating, Refrigerating and Air-Conditioning Engineers
BASE	-	Building Assessment Survey and Evaluation
DOE	-	Department of Energy
FOAF	-	Fixed Outdoor Air Fraction
HVAC	-	heating, ventilation and air-conditioning
IAQ	-	Indoor Air Quality
IEQ	-	Indoor Environmental Quality
IHEC	-	Integrated Human Exposure Committee
NAAQS	-	National Ambient Air Quality Standard
PM	-	particulate matter
SAB	-	Science Advisory Board
VAV	-	variable air volume
VOC	-	volatile organic compounds

APPENDIX B - DESCRIPTION OF AIR HANDLING SYSTEMS

CV - This is one of two types of air handling systems that were modeled. In the constant volume (CV) system the volume of supply air is set to satisfy the design cooling requirement of the system. Once this is established, the supply air volume remains constant. The temperature of the supply air which is delivered to the zone is varied in order to met the daily and seasonally varying cooling and heating needs. The dual duct CV system was modeled in the EPA project. In this system, two main ducts are used to distribute a constant volume of supply air to each zone. One duct is maintained at a relatively cool temperature (e.g., 55^{o}F) to provide cooling as needed while the other duct is maintained at a relatively hot temperature (e.g. 110^{o}F) to provide heating as needed. The hot and cold air streams are proportionally mixed at each zone to a temperature that will meet the heating or cooling load of that zone.

VAV - This is one of two types of air handling systems that were modeled. The variable air volume (VAV) system is a single duct system with reheat coils at each zone. The temperature of the supply air at the air handler is held constant, while the volume of supply air is varied in response to daily and seasonal variations. The volume of air delivered is dependent on the cooling and heating requirements of the zone. The supply air delivered to a zone is thermostatically controlled by a VAV box serving that zone. Heating is provided at each zone on an as-needed basis by a reheat coil in the VAV box. During off-peak conditions (*i.e*,. mild weather), most zones are operated at reduced supply air flow. This results in reduced total system supply air. The air handler must constantly adjust the total supply air flow provided in order to meet the combined needs of the individual zones.

APPENDIX C - EDITORIAL COMMENTS ON THE ORIA PROJECT REPORTS

The general characteristics of Base Buildings presented in the Exhibit 1 of the executive summary are not consistent with the Exhibit 3 of the Project Report #1. In the first exhibit, the office building has 11 floors, each floor height is 12 ft. and the total floor area is 250,000 ft^2; while in the second exhibit, the same office building has 12 floors, each floor height is 15 ft. and the total floor area is 338,668 ft^2. For the same building, the occupant density in the first exhibit is six, while in the second exhibit is seven. The infiltration rates for education and assembly buildings are 0.5 each in the first exhibit, but it becomes 0.25 in the second exhibit.

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