<u>**Initial Analysis of IES Wind Study for 601 Forest**</u>

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I am providing the following brief comments to the Ann Arbor City Council based on my initial analysis of the “601 Forest External Wind Study” done by Integrated Environmental Solutions (IES).

The report provided by IES is extremely limited in substantive content. Only four of the seven pages give any information at all substantively relevant to a wind study of the proposed building. Nevertheless, based on the brief IES report, the following technical observations must be made:

1) The extremely limited content of the report suggests this has been a largely perfunctory wind study. As described below, the information given in the IES report is insufficient to determine what was actually done in the study. This undermines the credibility and utility of the report and of the study itself.

2) It is well known that the output of CFD simulations reflect the inputs and the geometry used, yet the report does <u>not</u> to provide enough real information to determine whether or not the results that it asserts will meaningfully reflect real wind effects produced by the proposed building. Specific shortcomings of the CFD modeling done by IES as described in their report are noted below.

3) The report says virtually <u>nothing</u> about the computer model that IES used for this study. To what extent were surrounding buildings included? Which ones? How large an area was simulated? Was it a three-dimensional model? What detail was included in the proposed building and the surrounding buildings?

4) The report says <u>absolutely</u> <u>nothing</u> about the numerical parameters used in the CFD simulations. Experts know that virtually any desired result can be produced with a CFD code by adjusting such parameters as the computational grid. How fine was the grid used by IES? How does this the grid scale compare with the scales of features in the urban area model? What turbulence model did IES use in the CFD code? Was the turbulence model varied among standard models to determine the uncertainty it produces in the results? What values did IES use for the constants in the turbulence models?

5) All of the factors in #3 and #4 above can have a tremendous effect on the results obtained from any CFD-based wind study. Reporting results from any such study without providing this information renders the results essentially meaningless. This is widely accepted in the technical community dealing with CFD analyses of various aspects of aerodynamics, including wind flows and building wind effects. At a minimum, IES should be asked to provide complete information about the factors noted in #3 and #4 above.

6) The report says absolutely nothing about what combinations of wind speeds and directions were used in the CFD simulations. Two pages are spent on the Ann Arbor Municipal Airport wind data, but then nothing is said about what cases were actually simulated in the IES study. How many different cases were run? What were the bulk wind speed and direction for each of these cases? Do these combinations adequately span the "95th-percentile worst case" conditions?

7) The correct way to conduct a wind study is to first conduct simulation cases for proper combinations of wind speeds and directions with the existing building in the urban area model, and then to repeat the same simulation cases with the existing building replaced by the proposed building. The differences between each pair of cases will then far more accurately reveal the wind effects created if the propose building were erected. Conspicuously, that no such comparisons appear to have been done by IES.

8) The brief IES report does not appear to address wind effects created at higher elevations near the top of the proposed building, where as noted in my earlier comments the building-generated vortices can create potentially dangerous buildup of ice and snow above pedestrians. It also does not address effluent dispersal effects noted in my earlier comments.

9) The IES report is narrowly confined to ground-level winds, and in view of the shortcomings of the report provides no meaningful assessment of even these wind effects of the proposed building. The IES report, and presumably the study itself, have relied solely on a CFD-based approach, and provide no validation data for the proposed building site. As noted in my earlier comments, a serious effort to determine real wind effects of a proposed building would combine wind tunnel data with adequately-conducted and adequately-reported CFD results to provide even the most elementary confidence in the reported results. Given the issues noted above, no real confidence in the results in the IES report is justified.

Recommendations:

- It is recommended that IES be required to address at least the issues noted in #3, #4, and #6 above.

- It is furthermore recommended that IES be asked to state if they conducted comparisons of the type noted in #7 above; if they have not then such comparisons should be required by City Council.

- It is also recommended that IES be asked if they conducted any wind tunnel measurements of the proposed 601 Forest development to obtain direct data on the accuracy of their CFD results; if they have not then such data should be requested.

Comments Regarding Wind Studies

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Purpose of These Comments

I am providing the following technical comments to the Ann Arbor City Council and other associated governing bodies on building wind effects in relation to the proposed 601 Forest project. Please note that I take no position either supporting or opposing the proposed 601 Forest project. Instead, my purpose is to provide information on health and safety issues associated with wind effects from buildings in urban spaces, and information on how wind effects can be assessed to determine their ground-level impacts on pedestrian comfort and safety, as well as their mid- to upper-level impacts on such factors as effluent dispersal from building exhausts and re-ingestion of pollutants that affect building indoor air quality.

Issues With Large and Tall Buildings

Buildings can dramatically alter the wind flow patterns around them, far more so than is commonly appreciated. High bulk wind speeds are not needed for buildings to produce very high local wind speeds in their vicinity, as discussed below. The extent of the resulting wind impacts of a building in an urban environment depend greatly on the height and footprint of the subject building, the massing of other structures around the building, and on local wind conditions. <u>In general, wind effects become more significant – and can even rise to the level of significant health and safety concerns – as building height increases, as building frontal area and total blockage area (footprint) increases, and in the presence of increasing density of surrounding buildings.</u>

In high-rise developments, the aerodynamic effects of a building and the resulting wind flow patterns can be very complex and potentially very strong. Their effect is not nearly as simple as the direct “channeling” of the wind that occurs if it blows down an urban street between buildings. While this “wind tunnel effect” can certainly occur under some combinations of wind direction and speed, the far larger and far more important wind effects created by a building instead result from the large and strong vortices that are formed by edges and corners of buildings at essentially all wind directions and speeds. Such strong vortices can form even under otherwise moderate or mild wind conditions.

These vortices are strong localized swirling wind motions that are formed naturally as a result of flow separation from exterior features of a building, including horizontal and vertical corners and edges of the building itself, as well as similar corners and edges of various exterior features such as cornices, awnings, and other embellishments found on buildings. Their scale is typically comparable to the building feature from which they are generated, and thus can range from a few feet in diameter to a hundred feet or more. Larger-scale vortices typically survive the longest, and since they typically have the greatest circulation (i.e., strength) they are of primary concern.

The vortices resulting from wind flow over and around a building can produce highly counter-intuitive and unexpected wind flow patterns, with wind speeds that can easily be a factor of twenty or more higher than the nominal bulk wind speed that generated the vortices. Moreover, these vortices can maintain their form while propagating over distances many times their own scale and much larger than the building's exterior length, due to their interactions with building exterior surfaces and with the ground for great lengths. Building-generated vortices can often become trapped in urban "canyons" formed between buildings on opposing sides of a street, and in such cases their axial extent can be very long.

Concerns About Pedestrian Comfort and Safety

It is these building-generated vortices that are of primary concern for pedestrian comfort and safety. The locally high wind speeds they generate can readily blow dust, sand, dirt, and debris into the eyes of pedestrians. They can make walking in certain areas around a building so uncomfortable, unpleasant, and even dangerous that these areas may be routinely avoided by pedestrians. They can also blow snow into accumulations so deep as to make pedestrian traffic difficult or impossible, especially near corners between sidewalks and building exterior walls. Secondary flow patterns produced by these vortices can trap blown matter such as dirt, debris, snow, and papers along sidewalks, where they are further blown by vortex-generated winds.

Concerns About Structural Damage

Beyond such pedestrian-level wind effects of building-generated vortices, the high wind speeds produced by vortices at mid- and upper-level heights above ground can damage or destroy features of the building itself. Awnings, cornices, and many other features protruding from buildings can be torn, broken off, or bent by the resulting locally high winds. Snow and ice can be forced to accumulate at large heights on building exteriors by secondary winds from these vortices. Accumulations of snow and ice can also be torn loose by these localized vortex-induced winds and fall onto sidewalks. In some cases, exterior building materials such as tiles and structural materials have even been torn off from buildings by these strong local air flow patterns and fallen onto sidewalks.

Concerns About Effluent Dispersion

In addition to building damage and the attendant safety impacts on pedestrians noted above, unanticipated wind flow patterns associated with the locally strong swirling motions produced by vortex-generated winds can also affect effluent dispersion from buildings. Effluents such as warm air and steam from heating and air conditioning systems can be driven to ground level despite being released from roof-top equipment. In some cases, re-ingestion of effluents by air intakes located substantially far from the emission site can prevent satisfactory operation of such systems. Offensive odors from dumpsters, garbage chutes, and other building systems can be carried by vortex-induced winds far from where they are generated and where they might otherwise not be expected to be found.

Currently, there are no widely accepted standards constituting specific thresholds for avoiding detrimental or otherwise dangerous wind effects and for maintaining adequate levels of pedestrian comfort and safety. Due to the close coupling between the building size and shape, the exterior features and embellishments on the building surface, and the proximity and size of surrounding buildings and streets, wind effects of buildings must be determined on a case-by-case basis. A standard sometimes used in the past is that a building produces a significant wind-related impact if it results in the occurrence at least one time per year of winds at ground-level, or at mid- and upper-levels, of greater than 36 miles per hour (mph).

Governing Authorities Require Architectural Wind Studies

In recent years, architectural wind studies are being increasingly demanded by local governing authorities to anticipate and mitigate problems of the sort described above. <u>It has been common for some time now to require developers proposing large and/or tall buildings in urban areas to conduct credible technical assessments of likely wind effects and to present these to the local governing authority.</u> Demands for such assessments are generally regarded as falling well within scope of a typical local governing authority's charter to ensure the health, safety, and well being of the public they serve.

<u>For reasons noted above, simple comparative studies or "back-of-the-envelop" analyses are grossly insufficient to provide realistic estimates of the complex vortex-generated wind flow patterns produced by a building for various bulk wind speeds and directions.</u> Such simplistic assessments are being increasingly rejected as urban areas become increasingly built up, and as the attendant wind effects on public health, safety and well being are consequently increasing. Similarly, claims that various "seat-of-the-pants" modifications have been made to a building exterior to mitigate wind effects are also being increasingly rejected. There are far more accurate and readily accessible methods available today to developers, at reasonable costs, to provide far more realistic assessments of the wind impacts of the projects they propose.

The Need for Wind Tunnel and Computer-Based Simulations

Specifically, modern building wind assessments are based on either or both of two key methods. The first is based on conducting wind tunnel measurements of the building effect in the local urban environment. A small-scale model is constructed of the local urban area including the proposed development and placed in a wind tunnel. The tunnel is operated at various speeds and the model is rotated at various angles relative to the oncoming air stream, and measurements are made of wind speeds at dozens or even hundreds of locations around the area. Standard scaling methods are used to scale up the wind tunnel measurement results to full-scale conditions. The model size must be large enough (typically 3-5 ft.) that the viscous effects of the air flow are representative of the actual full-scale conditions.

<u>Numerous wind tunnels exist for such purposes and are available to the developer or to engineering firms acting on their behalf to conduct such measurements.</u> The University of Michigan's Department of Aerospace Engineering, for example, has such a wind tunnel with a 5-ft. x 7-ft. test section that has been used for architectural wind studies in the past. The wind impacts produced by the Ford headquarters building, for example, were determined in this manner in the UM 5-ft x 7-ft wind tunnel. Other universities, national laboratories, and commercial entities also have wind tunnels that are typically available on a user-fee basis for such building wind studies.

The second method uses computer-based simulations of the local urban environment to determine the wind effects that a building will produce. A computer model is generated of the urban area, and the fundamental differential equations of physics that govern air flow are simulated on the computer for various bulk wind speeds and directions to determine the resulting wind flow patterns at pedestrian-level as well as at mid- and upper-levels. Numerous consulting firms with access to the required technical expertise and facilities exist to provide such simulation capabilities to developers, and such simulations are being increasingly required for architectural wind studies.

These computer simulations must use various sub-models to account for the physics of key aspects of the wind flow, such as the viscous boundary layers that form on all exterior surfaces and features of the building and the separation of these layers to form into building-generated vortices. Since these models can introduce uncertainties in the accuracy of the computer-generated results, the most reliable method for assessing building wind effects is to use computer simulations for most of the combinations of bulk wind speeds and directions, and then augment these with wind tunnel measurements for a few key cases to provide validation of the computer predictions. This combined approach is generally the most cost-effective and reliable method.

The Value of Unbiased Wind Tunnel and Computer-Based Simulations
Based on the results from such wind tunnel measurements and computer simulations, the local governing authority can objectively understand the wind effects that will be produced by a proposed building. This approach allows otherwise biased claims either for or against a development to be replaced with objective technical information that allows the governing authority, the developer, the citizenry, and surrounding businesses to quantitatively understand the effects that a building will produce. It also allows the governing authority to make judgments based on solid technical information that are far less likely to be subjected to legal challenges by those for or against the development.

Moreover, using the results from such wind tunnel measurements and computer simulations, the developer and the local governing authority can develop mitigation solutions to address objectionable wind effects that are revealed by the wind tunnel measurements and computer simulations. Here too, demands by the governing authority for modifications to the proposed development are far less likely to be subjected to legal challenges by the developer, and are far more likely to alleviate concerns over wind effects by the local citizenry.

This approach allows objectionable and potentially dangerous wind effects from a proposed development to be assessed and addressed in a technically accurate way that is fair to the developer, to the citizenry, and to the local governing authority.

Respectfully,

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Education

I have a Ph.D. degree from Caltech in Aeronautics, where I specialized in the fluid dynamics of turbulent mixing and where I was the Donald Wills Douglas Fellow and received the William F. Ballhaus Dissertation Prize. I also have an M.S. degree in Mechanical Engineering from The University of Tennessee Space Institute (UTSI), and a B.S.E. degree in Engineering with a Mechanical Engineering concentration from The University of Alabama in Huntsville (UAH).

Work Experience

I am a Professor of Aerospace Engineering in the College of Engineering at The University of Michigan, where I also serve as Head of the Laboratory for Turbulence & Combustion (LTC). My area of technical specialization is fluid dynamics in general and turbulent mixing in particular. I have extensive experience in analyzing the mixing properties of fluid flows in general, and turbulent flows and turbulent reacting flows in particular. In the 23 years that I have served on the faculty at Michigan, I have performed extensive teaching, research, and consulting on these and other matters related to turbulent flows. I have taught various aspects of fluid dynamics to nearly two thousand engineering students, ranging from undergraduates and Master's students to Ph.D. candidates, and I have supervised the doctoral dissertations of numerous Ph.D. students in various aspects of advanced fluid dynamics in general and turbulent mixing in particular.

During this time I have continuously conducted research on various aspects of fluid dynamics and turbulent mixing, and have published widely in the leading national and international archival technical journals on matters of fluid dynamics, turbulent flows, turbulent mixing, and related areas. I have also served as an Associate Editor for one of the leading archival technical journals in this field, and as a Member of both the Publications Committee and the Executive Committee of the Division of Fluid Dynamics (DFD) of the American Physical Society (APS). I have also served extensively as a reviewer of technical papers and books related to fluid dynamics, turbulent mixing and related areas, as an organizer and advisor for national and international conferences in my area of specialization, as an invited and plenary speaker at numerous technical conferences, and as an invited speaker in the area of fluid dynamics at the leading universities and research organizations in my field throughout the world.

I have been made a Fellow of the Division of Fluid Dynamics of the American Physical Society (APS) in recognition of exceptional scientific achievements in the field of fluid dynamics in general and turbulent flows in particular. This is an honor bestowed on no more than one-half of one-percent of the active membership of APS, which is itself composed of leading researchers in physics and engineering sciences, and represents the foremost professional technical society in the field of fluid dynamics. I have also been made a Fellow of the American Institute of Aeronautics & Astronautics (AIAA) in recognition of scientific achievement in the field of fluid dynamics and turbulent flows; this honor is bestowed on no more than one-quarter of one percent of the active membership of AIAA, which is composed of leading researchers in aeronautics and closely related fields, including fluid dynamics and turbulent flows. I am also a member of the American Society of Mechanical Engineers (ASME), the Combustion Institute, and the European Mechanics Society.

Prior to joining the faculty at Michigan I worked as a Research Assistant in fluid dynamics and turbulent mixing at Caltech, where my doctoral research and dissertation dealt with experiments on mixing in turbulent flows. Prior to that I worked in industry as a Research Engineer in fluid dynamics at the U.S.A.F. Arnold Engineering Development Center (AEDC), as a Research Assistant in fluid dynamics at UTSI, and as a Research Assistant in fluid dynamics at UAH.

I have also served extensively as a scientific advisor for the U.S. government on matters related to my field of expertise. I currently serve as a Member of the Air Force Scientific Advisory Board (AF SAB) for the Office of the Secretary of the Air Force (SecAF) and the Air Force Chief of Staff (AF/CS), and have previously served as a consultant to the Defense Science Board (DSB) for the Office of the Undersecretary of Defense for Acquisitions and Technology (OUSD A&T), as a Member of the Defense Science Study Group (DSSG) for the Defense Advanced Research Projects Agency (DARPA), and as a consultant for the Institute for Defense Analyses (IDA).

Publications Within the Last Ten Years

I am an author or coauthor of over 170 journal articles, conference papers, technical publications, and book chapters, a holder of several U.S. patents, and have given over 220 technical presentations and over 100 invited and plenary lectures worldwide, in areas related to fluid dynamics, turbulence and turbulent mixing.