PERTURBATIONS IN ATMOSPHERIC DENSITY CAUSED BY HIGH RISE BUILDINGS AND THEIR EFFECT ON ASTRONOMICAL OBSERVATIONS - A CASE STUDY

by

Richard E. Kirts and Calvin A. Kodres
U.S. Naval Civil Engineering Laboratory, Port Hueneme, Ca 93043

ABSTRACT

Proposed construction of high rise buildings near the U. S. Naval Observatory in Washington D.C. caused astronomers to ask what effect the heat released by these buildings would have on their ability to make accurate observations. Models of the thermal perform ance of the proposed buildings were developed and used to estimate the rate of heat release to the atmosphere. The building heat release rates, along with other data, were input to a finite volume fluid mechanics computer program which was used to model the atmosphere near the Naval Observatory. The atmospheric model produced estimates of the gradients in air density above the Observatory. From these air density data it was estimated that the proposed construction would diminish the accuracy of the Observatory's measurements by a factor of several times the currently acceptable error.

INTRODUCTION

Located on 72 acres in downtown Washington D.C., the Naval Observatory has been measuring the motions of the stars and planets, keeping the nation's time, and providing astronomical data for navigation since the early 1800's. These data are essential to the navigation of ships, aircraft and spacecraft. No other astronomical observatory in the U.S. provides this service. But the Naval Observatory's ability to continue to make precise celestial readings was recently threatened by the proposed construction of several high-rise office and apartment buildings along the boundaries of the Observatory grounds. Astronomers suspected that thermal pollution caused by the proposed buildings would seriously affect their ability to make accurate observations.

METHOD OF SOLUTION

The approach used to investigate the problem was to (1) model the proposed buildings to determine how much solar energy is stored in the building shell during the day and how it is released to the atmosphere, (2) estimate the amount of heat released into the atmosphere by mechanical equipment such as air conditioning condensers, (3) use the heat flux as input to a comprehensive fluid mechanics program to determine how the heated air mixes with the surrounding atmosphere, (4) calculate contours of constant air density in the atmosphere near the Observatory and (5) calculate the change in anomalous refraction (and thereby observational error) from the density contour data.

Building Modeling

One of the first steps is to estimate the temperature of the exterior of the proposed buildings. This was accomplished by developing a computer program that solves the finite difference approximation of the equations governing heat transfer to and through the building walls. The program uses a fairly elaborate model (reference 1) of the solar radiation incident upon the walls and roof. Beam, diffuse and reflective solar radiation are all considered, as is shading. The energy incident on the wall is converted into heat, which is re-radiated to the surroundings, carried away to the atmosphere by convection, or conducted to the interior of the wall.

Typical simulation results for one of the proposed high rise buildings are shown in Figure 1.

Although a specific design was proposed for the high rise buildings, there are several negotiable design features which have a significant effect on the thermal signature of a building. Consequently, the building thermal model was used to study the effects

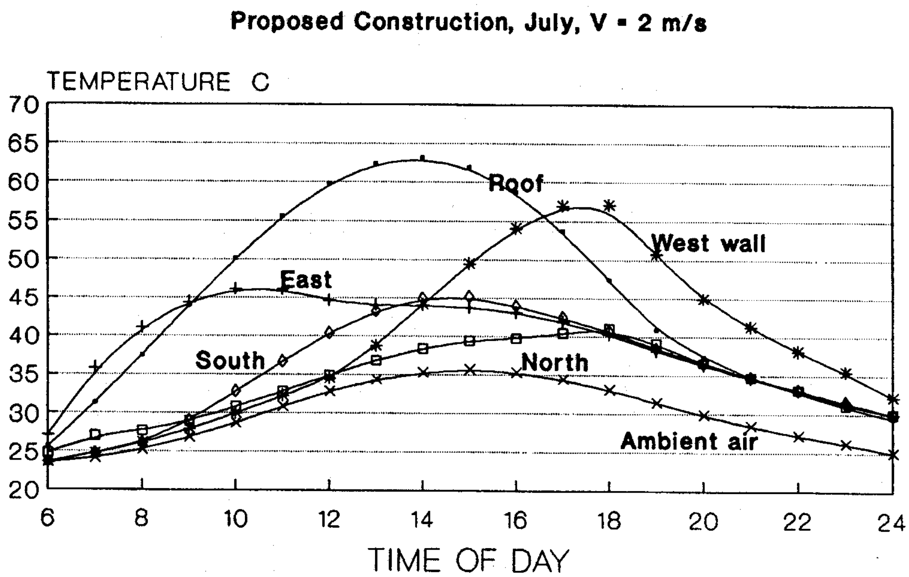

Figure 1. Typical building simulation results.

these design variables on building skin tempera-
ire. It was anticipated that three variables deter-
ine the thermal performance of walls: the heat
ɔsorbing properties of the surface material, the
ɜat storage properties of the facade, and the ther-
al resistance of the insulating layer. Specific
'operties of interest are the absorptivity of the wall
ırface in the short wave length region (< 1 micron)
pical of solar radiation, the heat capacity of the wall
›xpressed as the product of the mass of the wall
aterial per unit area and specific heat of the facade
aterial), and the thermal resistance (R value) of the
sulating layer of the wall. The sensitivities of wall
ermal performance to variations in absorptivity,
ɜat capacity, and R value were determined by
aking computer simulations of wall thermal perfor-
ance, varying one parameter at a time.

ɿe results of the wall thermal performance sensitiv-
ʳ studies are presented in Figures 2 and 3. These
sults are for the probable worst case: the west wall
the month of July. Figure 2 shows that, as
‹pected, the peak wall temperature decreases as
e absorptivity of the wall decreases. A value of
ɔsorptivity of 0.3 corresponds to a light painted
ırface. Figure 3 shows that if lighter, less massive
all construction is used, the peak wall temperatures
ill be higher, but the wall looses heat quickly to the
ırroundings after the sun sets. The resistance of
e wall (in the range of resistances examined) has
tle effect on the surface temperature of the wall
ɜference 1). The wall surface temperature does
crease as the thermal resistance is increased, but
the effect is negligible compared to other effects.

The proposed buildings would also release heat into the atmosphere from their mechanical equipment, such as air conditioning condensers and boilers. To predict the quantity of heat released by HVAC equipment, the building heating and cooling load were estimated. The load prediction was done using a commercially available HVAC load calculation program.

Atmospheric Modeling

Once the skin temperature of the building as a function of time has been estimated, the rate of heat convected from the building walls and roof to the atmosphere can be calculated. The heat and mass released by the mechanical equipment are added to the heat convected from the building.

Typical calculated heat release rates from the proposed building dur ing a late afternoon (wind from the west at 2 M/s) are presented below:

	Heat Release Rates, Q (MW)	
	July	January
Sides	1.90	1.12
Roof	2.20	0.44
Mech	0.62	0.23
Total	4.72	1.79

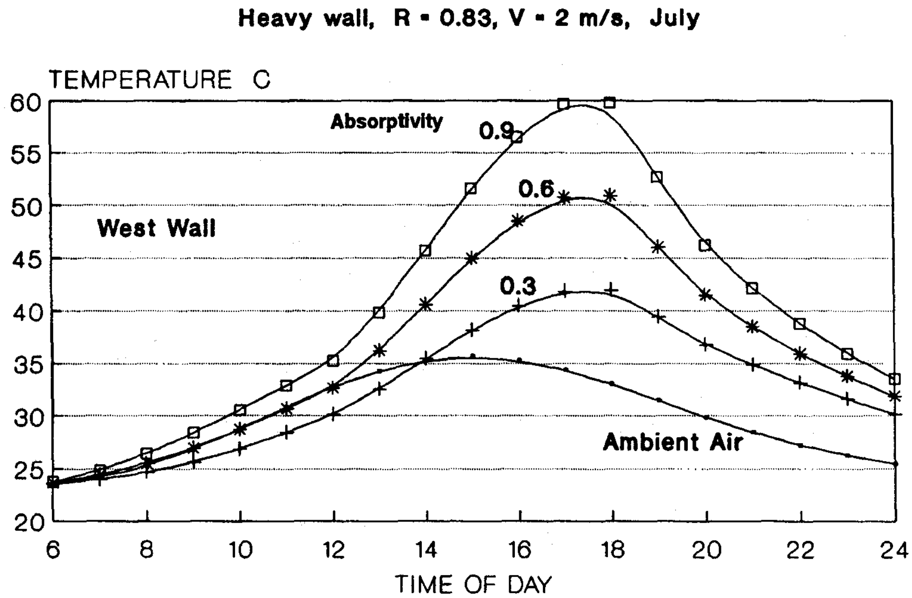

Figure 2. Thermal performance sensitivity to absorptivity of solar radiation.

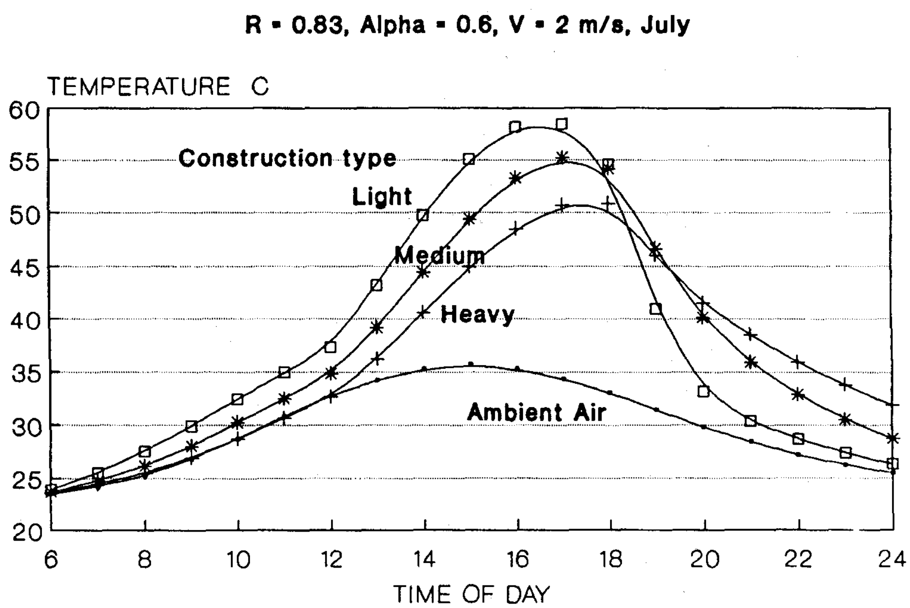

Figure 3. Thermal performance sensitivity to different wall construction types.

The wind blowing over the building is heated by the energy convected from the warm walls and roof of the building and the energy released by the mechanical equipment. This heating causes localized changes in the properties of the atmosphere. In particular, the local density of the air will decrease and the air will rise due to increased buoyancy. In addition, the wind will carry this rising column of air in the downwind direction. Buoyancy forces plus turbulence of the air cause mixing, which adds to the complexity of the structure of the atmosphere downwind of a building.

The heart of the problem then is to determine the structure of the air downwind of the proposed new construction and in the vicinity of the Observatory. The structure was modeled through the use of a general purpose finite volume fluid mechanics computer program called PHOENICS (reference 2).

RESULTS

Isopycnics

To determine the effect of the thermal plume from the proposed high-rise buildings on the accuracy of the observations of the Naval Observatory, it is necessary to examine how the density above the Observatory is affected. PHOENICS computes the density of the air in each computational cell. Therefore, a diagram showing air density characteristics near the Observatory can be constructed by connecting the center points of cells having equal air density. These lines of constant air density are called isopycnics. Figure 4 shows the general geometrical relationship between the Naval Observatory and the proposed building. Figure 5 presents isopycnics for the baseline case of: (1) single high-rise building as proposed by

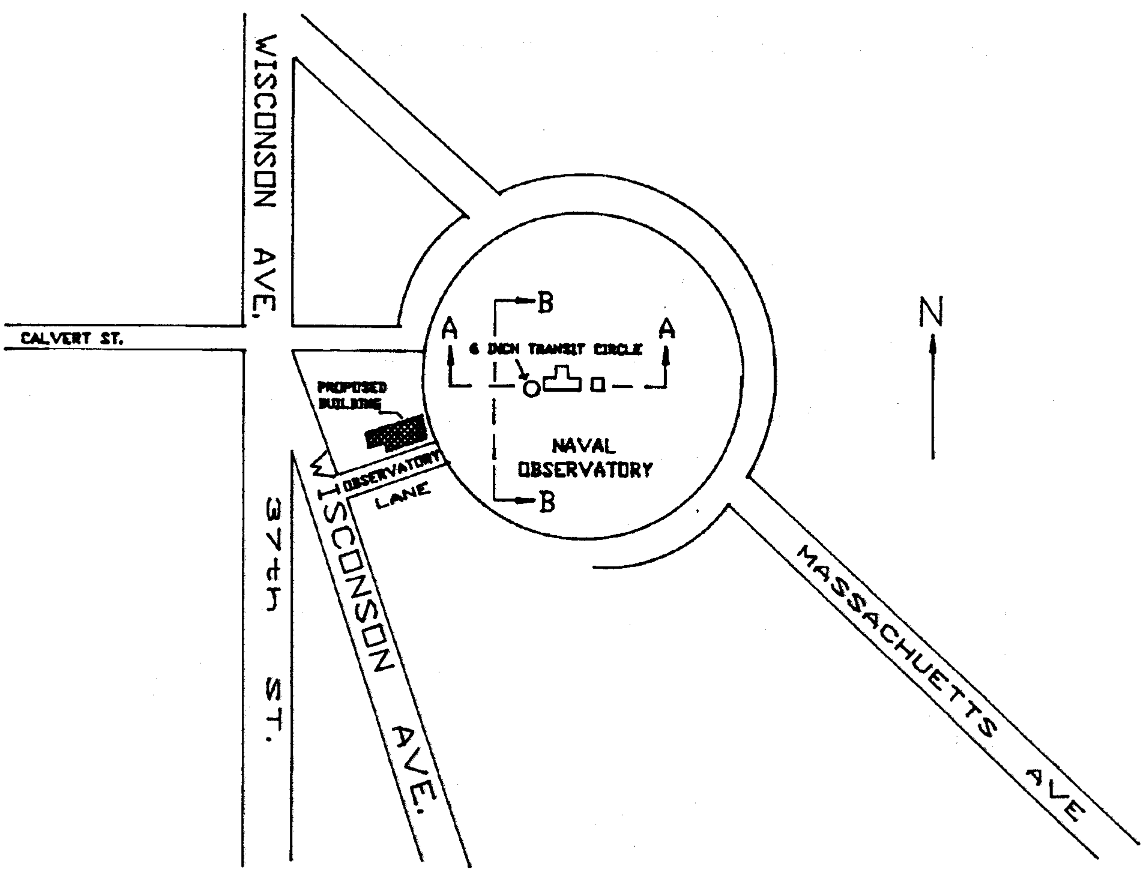

Figure 4. Map of vicinity of Naval Observatory.

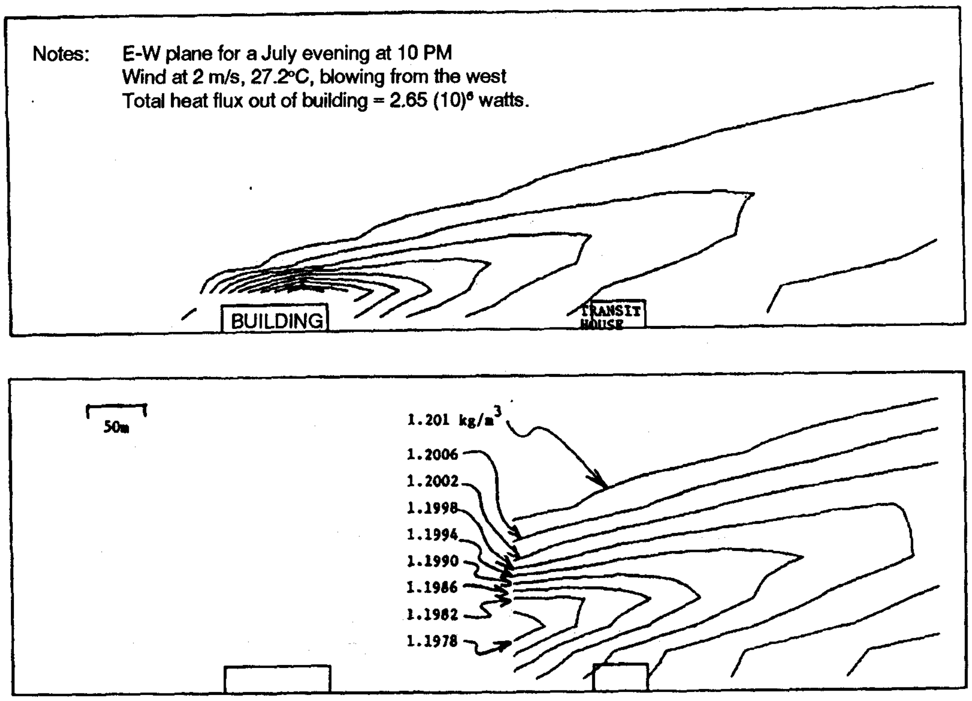

Figure 5. Predicted isopycnics (kg/m³) in the vicinity of the Naval Observatory induced by proposed building.

developer (2) late evening (10 P.M.) in the month of July and (3) wind from the west at 2 m/s. These isopycnics are in the east-west plane (plane A-A in Figure 4). As Figure 5 shows, the plume rises, spreads, and cools as it moves from the high-rise to the Observatory.

Also of interest is the impact of development on the Observatory if all of Wisconsin Avenue in the vicinity of the Observatory were to be developed to the extent allowed by current zoning regulations. For this case, buildings of several sizes were placed along Wisconsin Avenue in accordance with published plans for future development. Isopycnics for this case (in the east-west plane through the Observatory) are presented in Figure 6. As expected, increased development caused increased thermal pollution as indicated by the significantly higher density gradients.

Observational Error

The amount of anomalous refraction that occurs when an object is viewed through the atmosphere depends on the rate of change of density with distance and the orientation of these density gradients to the viewer. Analysis done by astronomers at the Naval Observatory using data for a single high-rise building (Figures 5 and 6) predicts an anomalous refraction of about 0.1 second of arc when looking straight up from the Transit Circle Telescope. The anomalous refraction error is a non-systematic error that cannot be eliminated by simply taking more observations or by applying statistical analysis.

Though this seems like a small error, the formal error in star position determined at the Naval Observatory is about 0.04 seconds of arc.

If development were to take place all along Wisconsin Avenue, the predicted anomalous refraction error is 0.3 second of arc. An error of 0.3 arc second on a mission to Saturn means that you would miss your destination by 1200 Km. Three tenths of an arc second on the Earth's surface is about 10 m. Unpredictable errors of this magnitude have serious implications for many military and commercial guidance and navigation systems.

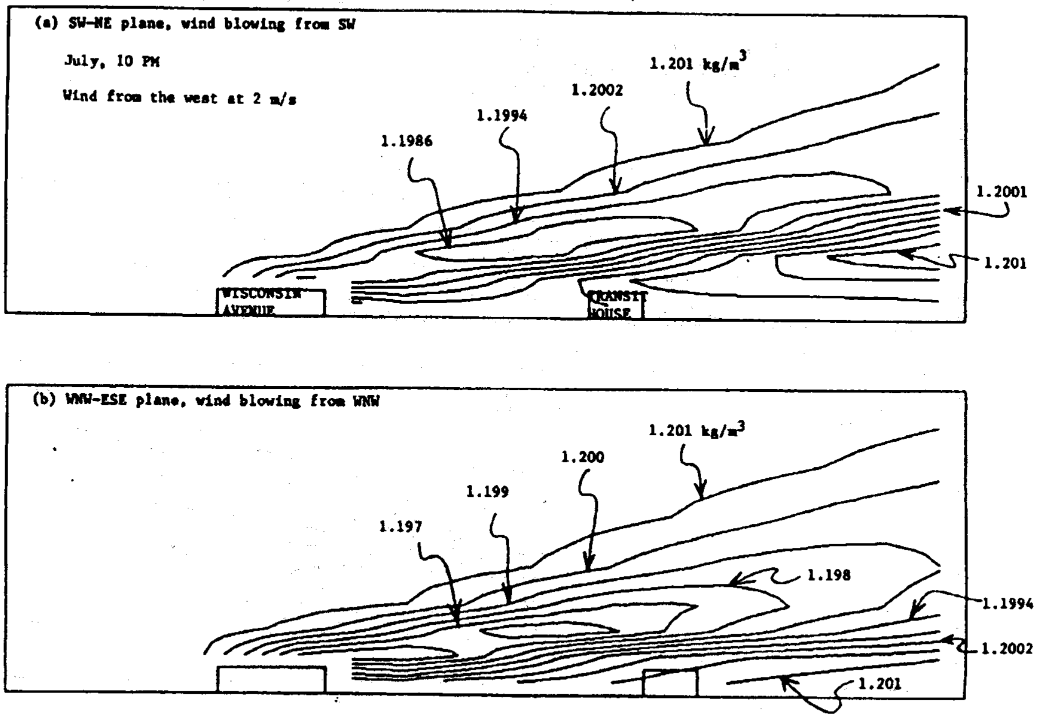

Figure 6. Predicted isopycnics near the Naval Observatory induced by multiple new construction on Wisconsin Ave.

REFERENCES

1. "Density Perturbations in the Atmosphere Above the Naval Observatory Induced by Heat Transferred Off Upwind Buildings", C.A. Kodres, U. S. Naval Civil Engineering Laboratory Technical Report, (in preparation).

2. "PHOENICS User's Guide", CHAM of North America, Inc, Huntsville, Al, Oct 1987