The "Greenhouse" Effect

R. Lee

College of Agriculture & Forestry, West Virginia University, Morgantown 26506

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The so-called radiation "greenhouse" effect is a misnomer. Ironically, while the concept is useful in describing what occurs in the earth's atmosphere, it is invalid for cryptoclimates created when a space is enclosed with glass, e.g., in greenhouses and solar energy collectors. Specifically, elevated temperatures observed under glass cannot be traced to the spectral absorptivity of glass.

The misconception was demonstrated experimentally by R. W. Wood more than 60 years ago (Wood, 1909), and recently in an analytical manner by Businger (1963). Fleagle and Businger (1963) devoted a section of their text to the point, and suggested that radiation trapping by the earth's atmosphere should be called "atmosphere effect" to discourage use of the misnomer. Munn (1966) reiterated that the analogy between "greenhouse" and "atmosphere" effects "is not correct because a large factor in greenhouse climate is the protection the glass gives against turbulent heat losses." In one instance, Lee (1966) observed that the net flux of radiant energy actually was diminished by more than 10% in a 6-mil polyvinylidene enclosure.

In spite of the evidence, modern textbooks on meteorology and climatology not only repeat the misnomer, but frequently support the false notion that the "heat-retaining behavior of the atmosphere is analogous to what happens in a greenhouse" (Miller, 1966), or that "the function of the [greenhouse] glass is to form a radiation trap" (Petterssen, 1958) (see also Sellers, 1965; Chang, 1968, and Cole, 1970). The mistake obviously is subjective, based on similarities of the atmosphere and glass, and on the "neatness" of the example in teaching. The problem can be rectified through straightforward analysis, suitable for classroom instruction.

Consider, for simplicity, an opaque surface with unit absorptivity and emissivity. The net flux of radiant energy $R_a$ (ly min$^{-1}$) at the surface under steady conditions can be symbolized as

$$R_a = R + 7.61 \times 10^{-16} T_s^4 - \sigma T_s^4,$$  \hspace{1cm} (1)

where $R$ is the incident shortwave flux. The second term is a form of Swinbank's (1963) estimate of longwave atmospheric radiation at the surface under clear skies at screen temperature $T_s$ (°K), and $\sigma T_s^4$ is the emitted longwave flux from the surface at temperature $T_s$.

Under a glass cover with shortwave transmissivity $t$ and with unit absorptivity to longwave radiation, the net flux at the surface is

$$R_{nu} = tR + \sigma T_s^4 - \sigma T_{nu}^4,$$  \hspace{1cm} (2)

where $T_s$ is the glass temperature and $T_{nu}$ the surface temperature. The difference

$$R_{nu} - R_a = [tR - R] + [\sigma T_s^4 - 7.61 \times 10^{-16} T_s^4]$$

$$+ [\sigma T_s^4 - \sigma T_{nu}^4]$$  \hspace{1cm} (3)

is the effect of the glass, i.e., the radiation "greenhouse" effect.

Evaluation of (3) demonstrates that radiation trapping cannot be responsible for observed temperature increases under glass. As an example, setting $T_s = 300$ K and choosing a conservative estimate of $t$, say $t = 0.90$ (Daniels, 1964) [under isothermal conditions $T_a = T_s = T_{nu} = T_w$], $R_{nu} - R_a = 0$ (approximately). At $R = 1.00$ and $1.20$ ly min$^{-1}$, $R_{nu} - R_a = 0.01$ and $-0.01$ ly min$^{-1}$, respectively.

Ordinarily isothermal conditions do not prevail, and, as a rule, $T_s > T_a$ and $T_{nu} > T_a$. The rate of change of longwave radiation emitted by the glass and surface is virtually 0.01 ly min$^{-1}$ (°K)$^{-1}$ in the range from 20–60°C, so the change in net radiation caused by temperature differences is

$$\Delta (R_{nu} - R_a) = 0.01(T_s - T_a + T_{nu} - T_{nu}).$$  \hspace{1cm} (4)

Since $T_{nu} - T_a$ can be expected to exceed $T_s - T_a$, the radiation "greenhouse" effect becomes increasingly negative as the temperatures increase. Moreover, only trivial deviations from (3) occur if the surface under glass is a graybody.

Elevated temperatures are observed in glass enclosures, in spite of a reduced radiation load, because convective losses are minimized. Since, for similar surfaces, heat losses to convection are proportional to the temperature difference $(T_s - T_a)$, or for a glass-enclosed space to $(T_s - T_a)$, convective losses from an enclosure are reduced by the ratio, $(T_s - T_a)/(T_s - T_a)$. If additional layers of glass are used (as in high-temperature solar energy collectors), losses may be further reduced.

The inevitable conclusion is that the oft-quoted radiation "greenhouse" effect does not apply to greenhouses, solar energy collectors, or other glass-enclosed spaces. The analogy with the atmospheric "greenhouse" phenomenon is correct only with respect to the glass, not with respect to the space enclosed.

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REFERENCES