Benefits of Reflective Roofs in Northern Areas of the U.S.

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Abstract

In the past few years, highly reflective roofs have been promoted to reduce the summer heat excursions associated with urban areas, and to reduce energy consumption associated with air conditioning. The benefits of highly reflective roofs have thus far primarily been focused on large urban areas in the south. However, this paper illustrates that reflective roofs are often beneficial in northern urban and rural areas of the U.S.

This paper discusses the following: benefits of reflective roofs, input conditions for evaluating whether a reflective roof should be considered, the winter penalty, influence of high R-value, and it provides conclusions and recommendations.

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His interest in energy-efficient buildings began during the 1973 Energy Crisis. He began conducting research on reflective roof surfaces in 1991.

BENEFITS OF REFLECTIVE ROOFS IN NORTHERN AREAS OF THE U.S.

INTRODUCTION

Long before the advent of air conditioning, people recognized that buildings with highly reflective roofs in hot, sunny climates offer greater occupant comfort than buildings with roofs that reflect very little solar radiation. With the introduction of air conditioning, occupant comfort was no longer dependent upon reflective roofs. Reflective roofs, however, were still beneficial because they reduced the cost of air conditioning. But with abundant supply of very low-cost electricity, the perceived importance of reflective roofs diminished. As the cost of electricity increased, more attention was given to reflective roofs in the southern areas of the U.S. Further general information on reflective roofs is provided in *Reference 1.*

In the late 1990s the roofing industry began to be come aware of urban heat islands and their impact.[2] This is the phenomenon wherein localized temperature excursions occur on sunny days in urban areas. The solar influence (i.e., the conversion of solar radiation into heat by absorptive surfaces of the built-environment) is a major cause of the increased urban temperature.[3] Highly reflective roofs have recently been promoted to help minimize the heat island effect. However, this emphasis has thus far primarily been on large urban areas in the South.

There is widespread misperception that reflective roofs are relevant only in the southern portion of the country, and that the urban heat island effect is only applicable to southern cities. However, reflective roofs are often beneficial in northern areas of the U.S. Although the benefits of reflective roofs are not as great in the north as they are in the south, specifying reflective roofs in many northern areas can result in reduced energy consumption, greater comfort for those who live or work in buildings that are not air conditioned, and improved air quality.

This paper discusses the following: benefits of reflective roofs, input conditions for evaluating whether a reflective roof should be considered, the winter penalty, influence of high R-value, and it provides conclusions and recommendations.

BENEFITS OF A REFLECTIVE ROOF

The type of benefits offered by a highly reflective roof (also known as a cool roof) are the same for both southern and northern areas. They include:

- Reduced energy consumption: Solar energy striking a roof that is not reflected is converted to heat. Hence, during winter, a roof with low reflectivity (or albedo) and no snow cover provides a warmer roof surface, which is desirable. But during hot weather, greater energy consumption is required to cool a building that has a heat-absorbing roof versus a highly reflective roof. To determine if a highly reflective roof reduces energy consumption cost for a specific building, the net annualized cost of heating and cooling the building needs to be evaluated, as discussed below.

- Enhanced occupant comfort: The temperature within non-air conditioned buildings is lower with a reflective roof versus a roof with low reflectance. The reduced interior temperature provides enhanced occupant comfort, and in some cases a reflective roof can be the difference between a person surviving or not surviving a heat wave. Appendix A discusses the large number of deaths that occurred in non-air conditioned houses in Chicago in 1995, and Appendix B discusses a program that was recently initiated in Philadelphia to mitigate heat-related deaths.

The benefits of a reflective roof on improved occupant comfort in buildings without air conditioning is also recognized by some workers. The labor contract at a manufacturing facility in Michigan stipulates that a reflective roof is required. Because of the stipulation, a roof consultant involved in reroofing the building was required to specify a reflective roof.

Most buildings are now air conditioned in southern areas of the U.S.; however, air conditioning was not so common a few decades ago. (The increased use of air conditioning likely was a significant contributor to the great increase in electrical power consumption between 1950 and 1980, as discussed in the next section.) A large number of buildings in northern areas of the U.S. are also now air conditioned, but it is probable that there is a greater number of non-air conditioned buildings in the north than in the south. For the non-air conditioned population of buildings, roof reflectivity can play a significant role in the health, comfort, and productivity of people within.

- Improved air quality: The urban heat island is a well documented phenomenon.[4] The phenomenon has been observed and documented since the early 19th century, but it was not until the relationship between heat islands and air pollution became evident that it began to receive increased attention from meteorologists and climatologists during the past 50 years.[5] The warmer dome of air over urban areas speeds up the chemical reactions that lead to high ozone concentrations and pollution.[6]

  The warmer air dome also causes increased use of electrical power for air conditioning. The urban temperature remains elevated well into the night because the overlying pollution inhibits urban heat loss, and because of the hot thermal mass of darker objects such as asphalt pavements and roofs with low-reflective surfaces. These factors place increased demands on power plants, which results in increased carbon dioxide emissions from the plants.[6]

EVALUATING WHETHER A REFLECTIVE ROOF SHOULD BE CONSIDERED

Before considering design input conditions for a specific building, it is important to have an understanding of the larger scale influences and site-specific influences.

Population and Electrical Consumption Increases over the Past 50 Years

The U.S. has an enormous electrical appetite. *Table 1* shows that over the last 50 years our demand for electricity has greatly exceeded our increase in population. Considering the implications of a great amount of electrical consumption, that building operations account for approximately 40% of the electricity used, and that the characteristics of a roof system can greatly influence a building's energy consumption, it is incumbent upon those involved in the roofing industry to take a more proactive role in advocating energy efficiency.

Year	Population Growth	Electricity Consumption Growth
1950-1970	19%	136%
1960-1970	13%	102%
1970-1980	11%	50%
1980-1990	13%	30%
1990-2000	13%	25%
1950-2000	86% (1)	1168% (2)

(1) From 151,325,798 to 281,421,906. (2) From 291 to 3,398 billion KWH.

Table 1: Growth in U.S. Population and Electricity Consumption, 1950 – 2000.

Note:

1. Population data are based on U.S. Census Bureau data (www.census.gov/dmd/www/resapport/states/unitedstates.pdf).
2. Electricity data are based on electric utility retail sales, as reported by the Department of Energy's Energy Information Administration's 1999 Annual Energy Review (www.eia.doe.gov/emeu/aer/elect.html). The data for the year 2000 are projected.

The recent lack of electrical power in California has heightened awareness of power shortages. But widespread power outages have hit northern areas as well. In July 1999, New York State experienced brownout when utilities reduced voltage by 5% because of excessive demand. At the same time, high demand resulted in rolling blackouts in New Jersey and Pennsylvania. That month 39 states reported above-normal weekly cooling degree days. In most instances the temperatures were well above normal. In Ohio the total cooling degrees for one week were 70% above normal, and in Illinois they were 48% above normal.[7]

The power outages have shown how much our daily lives depend upon electricity. People have been stranded in elevators, car accidents have occurred because traffic signals were not working, and businesses have been shut down. In 1998, a power outage shut down an automobile manufacturing plant in Ohio—2,700 workers were sent home.[7] Whether a small retail store, a consulting firm, a contracting firm, or a major manufacturing plant, these interruptions can have severe economic impact on those affected.

Global Warming

Globally, it is very likely that the 1990s were the warmest decade, and 1998 the warmest year since the beginning of instrumental records in 1861. A report released in January 2001 by the Intergovernmental Panel on Climate Change (jointly sponsored by the United Nations Environment Programme and the World Meteorological Organization) projects a globally averaged surface temperature increase of 2.5 to 10.4 degrees F over the next century. It also reports that most of the warming over the last 50 years is attributable to human activity.[8]

Increased temperatures will result in increased air conditioning demands. Reference 2 reports that on warm afternoons in Los Angeles, the demand for electrical power increases nearly 2% for every degree F the daily maximum temperature rises. In northern cities the range may vary, but the same ratio between power demand versus temperature is plausible.[9] New power plants will be needed to meet the demands related to increased temperatures, as well as demand related to increased population. Unfortunately, the carbon dioxide emissions from these new plants will further contribute to global warming.

Influence of Northern Heat Islands

The heat island phenomenon is normally thought of as being applicable to large urban areas in the south, such as Atlanta, Dallas, or Los Angeles. However, many northern cities also experience this phenomenon. As in the south, roof temperature on sunny summer days is largely a function of the reflectivity of the roof's surface. For example, in Salt Lake City a new black EPDM roof had a surface temperature of 170° F, while a white TPO membrane on a nearby building had a temperature of less than 100° F.[10] At NRCA's APP Weathering Farm in the Chicago area, through 1997, the hottest day occurred on July 13, 1995 (see Appendix A regarding the deaths that were associated with this heat wave). The ambient temperature was 104° F. The roof had three types of reflective coatings, with reflectivities of approximately 0.47, 0.46 and 0.31 (the coatings were a little over four years old). The temperature on the underside of the membrane was 141° F, 153° F and 152° F. The uncoated membrane had a reflectivity of approximately 0.09 and a temperature of 171° F.[11]

Computer simulations suggest that sunny summer afternoons in Chicago, Philadelphia, New York City, and Washington, DC can be 3.6° F warmer than their surrounding rural areas.[12] Simulations suggest that the increased urban temperatures increase the peak electrical demand by 5.4% in Chicago, New York City, and Washington, DC, and 2.8% in Philadelphia. Simulations also suggest that large-scale increases in reflectivity (primarily roofs and pavements) and vegetation can result in afternoon temperature reductions of 1.8° F in Chicago, Philadelphia, and New York City, and 0.9° F in Washington, D.C.

Reference 13 also reports on computer simulations. Eleven cities were included in this study. They were selected because each city has significant heat island problems. The 11 cities had a total population of 69.8 million people, with 55% living in the following northern cities: Baltimore/Washington DC, Chicago, Philadelphia, and New York City. The simulations assessed the annual heating and cooling energy consumption and peak electrical demand. The simulations were based on existing metropolitan-scale roof reflectivities versus modified roof reflectivities of 0.55 for residential and 0.7 for commercial buildings. The simulations indicated that with the increased roof reflectivity, all of the northern cities had net energy savings and reduced peak electrical demand. The projected savings did not account for the additional savings associated with the reduction of the ambient temperature associated with the modified roof reflectivities (i.e., a reduction in the heat island affect). In addition, the savings were under-predicted because snow cover and peak electrical demand charges were not considered. The study concluded that reflective roofs can also be encouraged in northern areas.

Reference 14 reports on computer simulations in Salt Lake City. This study focused on three building types believed to offer the greatest savings in annual energy consumption, peak electrical power reduction, and reduction of carbon dioxide emissions from power plants. The buildings included single-family residences, offices, and retail stores. For all three building types, the simulation used an R-11 for the base case, and an R-30 for the enhanced case. The base case reflectivity was 0.2. For the enhanced case, a reflectivity of 0.5 was used for residential and 0.6 for the commercial buildings. The enhanced case reduced the annual energy consumption, the peak electrical power demand, and the carbon dioxide emissions. The simulation showed that the enhanced case in conjunction with the addition of shade trees reduced the maximum urban air temperature by 3° F. As with the simulations in Reference 13, since snow cover was not considered, the savings were under-predicted.

Many assumptions go into the simulations reported in *References 12, 13* and *14*. The actual urban temperature excursions, their influence on electrical demand, and the magnitude of potential electrical savings associated with increased roof reflectivity are debatable. However, it is clear that in many urban areas (north and south), the heat island phenomenon occurs and it significantly contributes to electrical demand during the summer. It is also clear that if the reflectivity is significantly increased on many of the roofs within many urban areas, the urban energy consumption and peak electrical demand will be significantly reduced.

Influence of City Size

Although heat islands are normally associated with large urban areas, *Reference 15* reports that towns with about 1,000 inhabitants exhibit the heat island phenomenon, assuming that 1.8° F is the minimum urban/rural difference of significance. *Reference 5* also concludes that small towns (less than 50,000 people) should not be ignored.

Weather Data

In mild climates and in climates with high demand for cooling and heating, the influence of roof reflectivity is not readily apparent. As a first cut in evaluating the appropriateness of a highly reflective roof in a northern area, in the author's opinion, if a site is in Region 3 or greater as shown on *Figure 1*, and/or the site has several sunny days during the summer with a maximum temperature in excess of the low 80s, further consideration should be given to specifying a highly reflective roof.

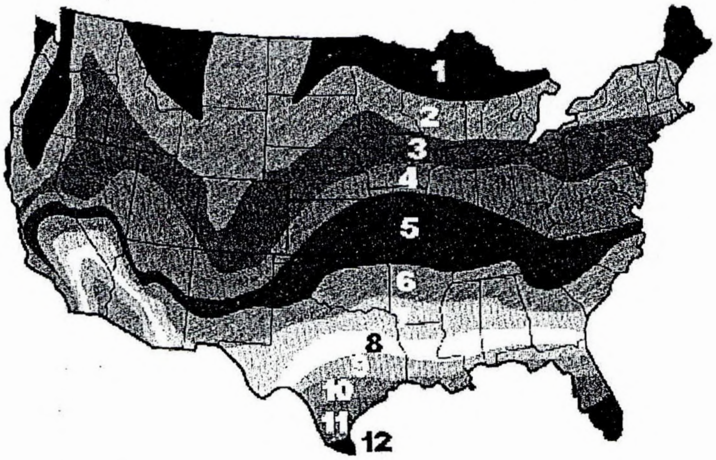

Figure 1: U.S. Climate Region Map, Cooling

Reprinted from Energy Star Consumer Investment Information, U.S. EPA, October, 1998.

For further evaluation, weather data for many areas can be downloaded from the National Climatic Data Center for a charge of $3.00 (as of 2001) per station. Go to www.ncdc.noaa.gov and click "most popular products," then click "most requested," then go to "local climatological data" and click "edited annual summary." Then select the desired station and click the latest year that is followed by "Annual" (e.g., *2000 – Annual*). Data are provided for normals, means, and extremes for 30 years. On the downloaded page that gives the "Normals, Means, and Extremes" for June through September, evaluate the normal and highest daily maximum temperatures, the normal cooling degree days, and the percent possible sunshine. Evaluation of these data will provide an indication of the severity of the summer temperature and solar radiation load.

For comparison purposes, *Table 2* provides climatological data for a few northern and southern cities.

City	June	July	August	September
Minneapolis	79°F NDMT	84°F NDMT	81°F NDMT	71°F NDMT
	137 NCDD	278 NCDD	192 NCDD	32 NCDD
	66% PPS	72% PPS	69% PPS	62% PPS
New York City	80°F NDMT	85°F NDMT	84°F NDMT	76°F NDMT
	203 NCDD	366 NCDD	326 NCDD	130 NCDD
	64% PPS	65% PPS	64% PPS	62% PPS
Seattle	70°F NDMT	75°F NDMT	75°F NDMT	69°F NDMT
	21 NCDD	64 NCDD	81 NCDD	24 NCDD
	56% PPS	64% PPS	65% PPS	62% PPS
Atlanta	86°F NDMT	88°F NDMT	87°F NDMT	82°F NDMT
	330 NCDD	428 NCDD	406 NCDD	241 NCDD
	67% PPS	62% PPS	64% PPS	62% PPS
Dallas	92°F NDMT	97°F NDMT	96°F NDMT	88°F NDMT
	480 NCDD	629 NCDD	617 NCDD	372 NCDD
	67% PPS	75% PPS	73% PPS	67% PPS
Phoenix	104°F NDMT	106°F NDMT	104°F NDMT	98°F NDMT
	696 NCDD	884 NCDD	822 NCDD	618 NCDD
	95% PPS	86% PPS	86% PPS	89% PPS

NDMT = Normal Daily Maximum Temperature **NCDD** = Normal Cooling Degree Days
PPS = Percent Possible Sunshine

All data were collected at airports, except New York City data, which were collected in Central Park. Compared to airport locations, higher temperatures would be expected in the urban areas. Normals are 30-year averages for 1961 to 1990.

Table 2: Climatological Data

Energy Costs

If evaluation of a site's weather data suggests that a highly reflective roof may be appropriate, the cost of cooling energy (usually electricity) and heating energy (usually natural gas) needs to be determined. Energy costs in different areas of the U.S. can greatly vary. The section on calculation procedures, below, discusses various calculation procedures for evaluating the appropriateness of a highly reflective roof. Rather than use the default utility values that are provided in the calculation procedures, it is recommended that local utility costs be used.

If local utility costs are obtained, it is important to determine if the electric utility assesses demand charges (or ratchets). For further discussion on demand charges, see *Reference 1* and *16*.

It is important to realize that although the heating load may exceed the cooling load in northern areas, the cooling costs may exceed the heating costs because many power plants use natural gas as the energy source to produce electricity. It takes about 5 BTU of gas to generate 1 BTU of electricity.

Calculation Procedures

If evaluation of a site's weather data suggests that a highly reflective roof may be appropriate, the estimated annual energy costs of the building with and without a highly reflective roof need to be calculated. In 1989, the Oak Ridge National Laboratory (ORNL) published a guide for evaluating the influence of roof reflectivity on annual heating and cooling energy use and cost for an individual building.[17] Default values for reflectivity of various types of roof surfacings are provided.

However, in lieu of the ORNL values, the author recommends that reflectivity data be obtained from the manufacturer of the surfacing product. A value after three years of field exposure is recommended. The value should be for an uncleaned surface, unless the designer believes the building owner will have the roof cleaned every three years. The guide notes that HVAC equipment efficiency (heating) and COP (cooling) have a wide range of values, depending upon equipment type, age, condition and size. It recommends that efficiency and COP values be obtained from actual data on the building's equipment, if possible. However, default values are provided. The guide includes energy costs, but these are based on 1985 data. If the ORNL data are used, demand-related costs are included in the calculation. If local energy costs are used in lieu of the default costs, demand costs (which can be significant) are not accounted for. The guide does not consider snow cover, rainfall, or shading (e.g., from trees or other buildings). It cautions that if the designer judges any of these factors to have significant impact, then the results from the calculations will be skewed. The guide also does not account for cooling savings associated with a reflective roof when fresh air intakes occur near the roof surface (this saving is not discussed in the guide). Although the guide has limitations, it is a useful tool. However, because the calculations are performed manually, it is not as user-friendly or fast as a recently introduced, web-based calculation procedure.

The new ORNL calculator for determining the economic benefit of reflective roof surfaces is found at www.ornl.gov/roofs+walls/. Once at the site, click "interactive calculators to get to it. As with the manual procedure, this calculator does not account for snow cover or winter roof surface temperature reductions caused by wind. Hence, the energy savings of a highly reflective roof will be under-predicted in areas where the roof is covered with snow for a significant portion of the winter. The calculator can be used as a "what-if" tool to assess energy consumption as a function of roof reflectivity and R-value. The calculator determines the heating and cooling differences separately; hence, the heating penalty associated with a reflective roof can also be evaluated.

After calculating the annual energy cost difference between a building with and without a highly reflective roof, the decision about specifying a highly reflective roof can be made, based on the annual energy costs and the cost difference (if any) between the two roofing options. The decision can also be influenced by the desire to have the roof assist in mitigating rather than contributing to the heat island.

EVALUATING THE WINTER ENERGY PENALTY OF A REFLECTIVE ROOF IN NORTHERN AREAS

When considering a highly reflective roof, it is important to be aware of its potential penalty during the heating season. During winter, a roof that absorbs a substantial amount of solar radiation is desirable. However, its benefits can be much lower than presumed. For example, if the roof is covered by snow, the snow nullifies the low reflectivity of the roof (fresh snow has a reflectivity of about 0.8 and old snow is about 0.4 to 0.7).[18, 19] Also during winter, the number of daylight hours is substantially reduced, the solar radiation is not as intense, adjacent taller buildings can shield the roofs of lower buildings because of the low sun angle, the winter months are often more overcast, and wind bleeds off much of the warmth of the roof surface. When the winter attributes of a roof with low reflectivity are carefully considered, in many locations the attributes are miniscule.

INFLUENCE OF HIGH R-VALUE

In most cases, roofs in northern areas have (or should have) a higher R-value than roofs in southern areas. The lower the R-value, the greater the benefit of a highly reflective roof during the cooling season. Therefore, the question arises, "is a highly reflective roof of value when the roof has a high R-value?" In terms of its influence on the heat island phenomenon, a highly reflective roof is beneficial, regardless of the roof's R-value. In terms of its influence on the cost of cooling the building (or improving the comfort in buildings without air conditioning), a highly reflective roof will be beneficial, but the magnitude of the benefit declines with R-value.

Reference 20 reports on a house in Florida that was instrumented before and after the roof was coated. The roof insulation had an R-value of 25. The roof reflectivity was 0.22 prior to coating and 0.73 after coating. Even with the high R-value, the highly reflective roof saved 4 kilowatt hours per day, which was an 11% savings.

Reference 21 reports on a research project in which black and white single-ply membranes were installed on test panels with R-11 insulation in Florida. Based on the temperature data collected, the cooling costs for a building with insulation ranging from R-1 to R-30 were calculated. Even with R-30 insulation and accounting for degradation of the initial reflectivity value of the white membrane, significant savings in cooling costs were predicted.

CONCLUSIONS AND RECOMMENDATIONS

A. A highly reflective roof should be considered in northern areas when there is a net annual savings in energy costs, or if the building is not air conditioned and it is desired to enhance occupant comfort during the summer.

B. In calculating the annual energy costs, if Energy Star® reflectivity values are used, use the three-year exposure value. However, be aware that the three-year value may be for a cleaned surface. Unless the roof designer believes the building owner will have the roof periodically cleaned, the designer should obtained three-year uncleaned values from the manufacturer. (For further information on Energy Star®, see www.epa.gov/appdstar/roofing/index.htm or *Reference 1.*)

C. In northern areas, a reduction in R-value should not be taken if a highly reflective roof is specified. In southern areas, it can be appropriate to reduce the R-value when a highly reflective roof is to be installed. But in areas with significant heating loads, the reduction is not prudent.

D. In those areas where heat island reduction is desirable, the reflectivity of cities needs to be gradually increased. Specifying highly reflective roofs for new buildings, reroofing projects and re-coating is an effective strategy to achieve this goal.

> Note: To illustrate forward thinking, Highland City (near Salt Lake City) recently incorporated highly reflective roof requirements into its zoning ordinance for a commercial area of the city that is now largely undeveloped.[22] The requirements were originally advocated by the architectural firm as one strategy in promoting the development of a more comfortable and healthier commercial area.

E. Heat island reduction considerations should not be limited to large urban centers. Incorporation of highly reflective roofs in small towns can also be beneficial.

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APPENDICES

Heat Wave-related Deaths in Chicago

The Midwest experienced a severe heat wave in July 1985. The Cook County Medical Examiner's Office (CCMEO) reported that over 500 cases of heat-related deaths occurred in Chicago that month. A follow-up study concluded that the heat wave appeared to contribute to nearly 200 more deaths than were attributed by the CCMEO.[23]

For the CCMEO to certify a death as heat-related, several criteria had to be met, including a measured body temperature of at least 105° F before or immediately after death, and evidence of high environmental temperature at the scene of death (usually greater than 100° F). *Figure 2* shows the relationship between the maximum exterior ambient temperature, the heat index (which is a function of exterior ambient temperature and humidity), and heat-related mortality, which peaked two days after the day of maximum temperature.

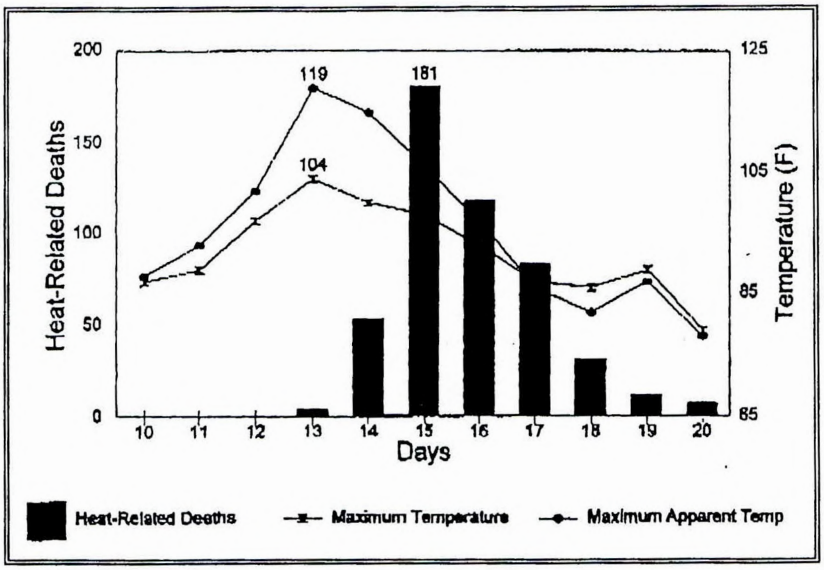

Figure 2: Heat-related Deaths and Temperatures, Chicago Residents, July 10 through July 20, 1995 **Reprinted from Reference 23.**

The heat wave had a disproportionate impact on the elderly. 72% of the heat-related deaths were accounted for by those 65 years old or older. Other important risk factors that were identified included living alone, living on the higher floors of buildings, living in poverty, and living without air conditioning. *Reference 23* also stated that "Chicago, like most urban centers, is prime target from heat mortality." It concludes that the heat mortality "problem will worsen unless we learn to intervene effectively."

Philadelphia Cool-Aid

Philadelphia experienced five of its hottest summers on record in the 1990s. Over 300 heat-related deaths occurred since 1993, including 52 Philadelphians who died in their homes in 1999. Most of the victims since 1993 were senior citizens. Typically people died in their own home, in a room with shut windows and no fan or air conditioner.

Following the deaths in 1999, the federal government provided emergency funds to the city to help low-income seniors and disabled people with one-time grants to pay their electric bills. New air conditioners and fans were also provided. However, those receiving the air conditioners and fans would be faced with higher electric bills in the future. This presented a problem for those who could not even pay their current utility bills.

To provide a more effective response to heat-related deaths, the Energy Coordinating Agency of Philadelphia initiated a program in early 2000. The goal is to prevent heat-related suffering and death of low-income, at-risk older adults, and to lower their energy bills by providing passive cooling. In the pilot phase, 400 homes will be treated.

Much of the at-risk population lives in brick row houses with smooth-surface (black), low-slope, built-up roofs. With closed windows (which is common), temperatures in the top floor reportedly can exceed 115° F on a day when the exterior ambient temperature is 95° F. Retrofit measures can include reflective roof coatings, insulation, window repairs, and whole-house fan installation. By the end of 2000, roofs on 82 houses had been coated with coatings that met the Energy Star® reflectivity criteria. Roof surface temperatures as high as 178° F were reportedly recorded prior to coating. After coating, the maximum roof surface temperature recorded was no more than 10° F above the ambient temperature.

Some of the homes were instrumented to evaluate the effectiveness of the building retrofits. The instrumentation was installed in the fall of 2000, so it will be later this year before findings are available.

In addition to building retrofits, Cool-Aid clients receive education to learn how to stay cooler without increasing their electricity usage, and there is on-going social contact to reduce social isolation.

For further information about the program, contact the Energy Coordinating Agency of Philadelphia, 1924 Arch Street, Philadelphia, PA 19103. Telephone: 215 988 0929, extension 238.