POTENTIAL OF TREE SHADE FOR REDUCING RESIDENTIAL ENERGY USE IN CALIFORNIA

by James R. Simpson and E. Gregory McPherson

Abstract. Electric utilities in California currently sponsor planting of approximately 75,000 yard trees annually as an energy conservation measure. In this study we evaluated the potential effects of tree shade on residential air conditioning and heating energy use for a range of tree orientations, building insulation levels and climate zones in California using computer simulation. Trees shading a home's west exposure produced the largest savings, both annual (kWh) and peak (kW), for all climate zones and insulation levels considered. Next largest savings were for southwest (annual and peak) and east (annual only) locations. Three trees (two on the west, one on the east side) reduced annual energy use for cooling 10 to 50 percent (200 to 600 kWh, $30 to $110) and peak electrical use up to 23 percent (0.7 kW). Except in climates with little air–conditioning demand, cooling load reductions were always greater than increased heating loads associated with shade from south side trees in winter. Air–conditioning savings, both peak and annual, were larger in warmer climates and uninsulated buildings; percentage savings were larger in cooler climates and for more energy efficient buildings. Recommendations are made regarding locating yard trees to maximize energy savings.

Strategically placed shade trees affect energy consumption for residential space conditioning by reducing solar gain. In summer, decreased solar thermal gain resulting from direct tree shade can reduce energy used for air conditioning. In winter, reduced solar access, even from leafless trees, can increase heating requirements. Nationwide, it is estimated that $10 billion is expended annually for residential cooling [1]; approximately $500 million is spent in California alone [4]. Therefore, even small percentage changes in cooling loads due to trees can have potentially large dollar impacts.

The effect of tree shade on cooling and heating loads depends on factors such as climate; tree size, shape and shading coefficient; direction and distance of trees relative to buildings; type, size and vintage of building construction, and occupant behavior [13]. (Shading coefficient refers to the fraction of solar radiation blocked, ranging from 0.0 when all solar radiation is blocked to 1.0 when all is transmitted). Measurements of shade effects on space conditioning have thus far been limited primarily to single buildings or scale models, due largely to the time and expense involved with monitoring large populations [19]. A review of four measurement studies with a range of experimental designs, building types, landscaping, and climates found measured air–conditioning savings ranged from 25 to 80 percent [19]. Larger savings were associated with more dense and extensive shading, and milder climates where solar radiation is often the predominant mode of heat gain.

More recently, Akbari et al. [2] measured peak demand and energy savings of 0.61 to 0.79 kW (25 – 50%) and 3.6 – 4.8 kWh/day (26 – 47%) for a heavily shaded home in Sacramento. Clark and Berry [5] found weekday demand savings during the summer of 0.17 kW (7%) for houses with air conditioners, and 0.35 kW (14%) for houses with air conditioners and evaporative coolers, in Phoenix, Arizona. The latter study measured whole house electrical use for 175 homes; a subsample of 24 had an average of 3 trees (24 inch box) planted nearby after data were collected without trees. Average peak (3 to 5 p.m.) whole house electrical demand for the entire sample was 3.55 kW; percentage savings were based on the assumption that air conditioning represents 70 percent of peak demand (K. Clark, Arizona Energy Commission, 1994, personal communication).

Factors that influence building energy use can be investigated by computer simulations. These show that shade from a single well–placed, mature tree (about 25 ft crown diameter) would reduce annual air–conditioning use by 2 to 8 percent (40 – 300 kWh) and peak cooling demand by 2 to 10 percent (0.15 – 0.5 kW) for cities across the U.S. [1,9,10,11,15,18,21,22].

Reduced solar access from winter shading can be appreciable even for deciduous trees, potentially increasing energy used for space heating [7]. Computer simulations [26] found that shade from street trees positioned 15 to 35 feet from a building's south side often increased annual (kWh) building energy use for combined space conditioning and hot water heating compared to the same building without trees. The effect was most pronounced for energy efficient homes with heavy window shading and solar–assisted hot water heaters than for more conventional homes, and for the cooler of the five California climate zones considered.

This paper extends Thayer and Maeda's analysis to 11 California climate zones, considers yard trees in a variety of orientations around a building, includes effects of building energy efficiency, and considers peak (kW) and annual (kWh) energy use. Shade on buildings from various tree configurations is calculated; results are used in an energy use simulation model to predict the effect of the tree shade on space conditioning.

Electric utilities in California currently sponsor planting of approximately 75,000 yard trees annually as an energy conservation measure, stimulating interest in quantifying their energy impacts. Information from studies of this type should suggest strategies useful for reducing peak generating requirements of electric utilities, developing energy–efficient landscape incentives for new construction, planning landscape retrofits for existing residential and small commercial buildings, and producing educational materials that deal with the design of energy efficient landscapes. Arborists, urban foresters, landscape professionals, utilities and utility sponsored nonprofits can employ the results as a basis for practical siting and selection guidelines for energy conserving trees.

Methods

Computer simulations. The relative effects of various landscape tree configurations on space conditioning use were determined from computer simulation. Shading of buildings by trees was determined using the Shadow Pattern Simulator (SPS) program [17]. SPS calculates hourly tree shade for each wall and roof surface based on building and tree sizes and their relative orientations and distance from buildings. MICROPAS ver. 4.01 [6] uses building thermal characteristics, weather data and information related to occupant behavior (described subsequently), combined with SPS results, to provide hourly estimates of building energy use. Energy savings are determined by comparing predictions for identical unshaded (base case) and shaded buildings. Since simulations may overestimate measured energy use [3], base case results were checked by comparison with residential energy use data available for Sacramento [2,25]. Dollar savings were calculated using local utility rates of $0.12/kWh for zones 2, 4, 11, 12 and 13 (except Sacramento County), $0.08/kWh for Sacramento County, $0.11/kWh for zone 7 and $0.13/kWh for zones 8, 9, 10, 14 and 15.

MICROPAS determines the peak day (defined as the day with the maximum hourly energy use value) based on calculated daily building energy use and California Energy Commission weather data. Peak demand or capacity (kW) is important to electric utilities in terms of providing enough generating capacity to meet demand, which is due to air conditioner operation for summer peaking utilities. Peak savings were calculated on the peak day for the hour with the greatest energy use; this occurred between 1300 and 1600 hours here (i.e., between 1:00 and 4:00 p.m.).

Weather data. Hourly shading impacts were simulated for residential structures in representative cities (Table 1) in 11 of California's 16 climate zones (Figure 1). These climate zones were developed by the California Energy Commission as part of its building energy efficiency standards, and are based largely on average dry bulb temperature [12]. Representative weather information for these zones is included with MICROPAS; average monthly and annual dry bulb temperatures are given in Table 2. Zones selected here had *utility sponsored tree planting programs and significant* cooling seasons (Table 1). The range of climates considered represent many cooling dominated climates in the United States, except for the hot/humid southeast. Hence, energy and demand savings presented as percentage differences from corresponding unshaded base cases here are expected to be representative of a wide

Table 1. Climate zone, base case annual (kWh) and peak (kW) electrical energy use for cooling, and peak and annual cooling savings summary for two trees on the west and one on the east for the energy efficient home.

Climate zone	Major city	Heating degree days[1]	Cooling degree days[2]	Base case cooling electrical use		Annual savings			Peak savings		
				kWh	kW	%	kWh	$	%	kW	Hour
2	Santa Rosa	3340	323	881	2.51	38	333	40	19	0.47	15
4	Sunnyvale	2366	325	539	2.29	52	282	34	21	0.49	15
7	San Diego	1355	472	418	2.07	49	206	23	10	0.21	14
8	El Toro	1586	638	1047	2.54	34	355	46	1	0.02	13
9	Burbank	1488	893	1410	2.91	29	403	52	17	0.49	15
10	Riverside	1570	1243	1929	3.13	23	438	57	7	0.23	15
11	Red Bluff	2518	1337	2135	3.34	26	548	66	21	0.69	16
12	Sacramento	2764	708	1490	3.18	34	513	62[3]	23	0.74	16
13	Fresno	2300	1908	2968	3.40	21	628	75	22	0.75	16
14	China Lake	2706	1719	2677	3.24	22	576	75	23	0.75	16
15	El Centro	776	4018	5875	4.08	11	642	83	11	0.46	15

[1]One heating degree day (HDD) accumulates for every degree that the mean outside temperature is below 65°F (18.3°C) for a 24 hr period.
[2]One cooling degree day (CCD) accumulates for every degree that the mean outside temperature is above 65°F (18.3°C) for a 24 hr period.
[3]$41 in Sacramento County

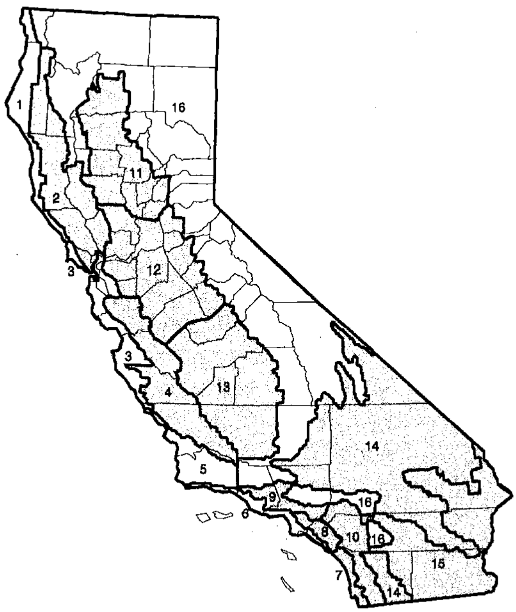

Figure 1. Climate zones of California.

range of housing types in California and also in regions of the United States where similar weather conditions are found.

Building characteristics. The base case structure, referred to subsequently as the energy efficient house, was a single story frame house with characteristics similar to California Energy Efficiency Standards (Title–24) for residential buildings. Salient features of such a structure include wall insulation of R19, ceiling insulation of R38, gas furnace efficiency of 78 percent, air conditioner seasonal energy efficiency ratio (SEER) of 10, and dual–pane windows with area equal to 16 percent of conditioned floor area. Other features were slab–on–grade construction with 1500 ft^2 conditioned floor area, windows evenly distributed on each wall, and walls oriented along compass cardinal directions. Cooling by natural ventilation was assumed when outside temperature dropped below the thermostat set point of 78°F.

The effects of three insulation levels on energy use with tree locations similar to those used here were simulated in climate zones 2, 4, 11, 12, and 13 [22]. Besides the 1) energy efficient house, an 2) attic insulated (R19 ceiling, R0 wall insulation) and 3) uninsulated house (R0 ceiling, R0 wall insulation) were analyzed. Only the energy efficient house was analyzed in remaining climate zones [18]. In preliminary simulations, percentage savings due to shade were found to be relatively constant when changes in building size were altered to produce absolute cooling energy use up to 50% less or 100% more than reported here, which indicates that current results can be expected to hold for a range of building sizes.

Tree selection and location. A single deciduous tree species, the Chinese Lantern Tree (*Koelreuteria bipinnata*), represented all trees in these simulations. This species is desirable in terms of solar control and access since it is deciduous, has a broad, umbrella shaped crown, is a low to moderate water user, moderately pest resistant, and a low emitter of volatile organic hydrocarbons. It was assumed that trees blocked 85 percent of incoming solar radiation when in leaf from April through November, and 30 percent during the December to March leaf–off period [13]. At planting (5 gallon stock) and years 5, 10, 15, and 20, tree heights were 6, 13, 19, 24 and 25 feet, respectively. Crown diameter was equal to tree height. Rate of growth decreased with age from 1.5 to 1 feet per year, which is an extremely conservative growth rate for this tree in California.

Impact of shade for single trees planted opposite east, south and west building walls, two trees opposite west wall, and three trees where two are opposite west and one opposite east walls, was investigated for all 11 climate zones. In addition, simulations for single trees located on building corners, and for seven trees opposite all building corners and walls (except north) were done for Sacramento. All trees were located 12.5 feet from the building. The north wall was excluded in all cases since negligible shading occurs there. Trees were placed so that their crowns, and therefore their shade on building walls, had little overlap.

Results

Simulations for the energy efficient building in Sacramento gave annual and peak cooling energy use of 1490 kWh and 3.18 kW. These results are in reasonable agreement with other studies in Sacramento when differences in building construction are accounted for. Sacramento Municipal Utility District (SMUD) estimates are 1200 kWh and 2.0 kW for Title 24 compliant buildings similar to those used here [25]. SMUD estimates are based largely on system–wide residential load data for large numbers of residential customers. This type of analysis tends to underestimate loads for individual buildings since homes where air conditioners are turned off are not accounted for. Peak capacity estimates from SMUD are averages from 1 to 8 p.m., therefore are expected to be lower than averages for peak hour only used here. Akbari et al. [2] using simulations calibrated with detailed measurements obtained 1050 kWh and 3.6 kW (averaged over four building orientations) for similar buildings. Lower values of kWh in their analysis may be related to their low window to conditioned–floor–area ratio of 10%, compared with 16% used here.

Effects of tree placement, numbers and age. Trees shading a west exposure from afternoon sun had the greatest impact on cooling savings for all climate zones and insulation levels. In Sacramento (climate zone 12), annual savings due to a single, 24 foot tall, 15 year old tree to the west of the building was 12 percent (180 kWh, $20) for an energy efficient house (Figure 2). Cooling savings from an east or southwest tree were approximately 50 percent less, and from a southeast, south or northwest tree 25 percent less than from a tree positioned on the west (a northeast tree had negligible impact). Savings decreased in approximate proportion to tree age (i.e., tree size), since younger trees shaded less wall area than older trees with larger crowns. For the preceding example, savings were approximately 4 (60 kWh, $5) and 8 per cent (125 kWh, $11) for 5 and 10 year old trees, respectively.

Savings from addition of a second tree on the west was 80 percent of that from the first tree; savings from east and west trees (e.g., comparing two west with two west and one east configurations) were approximately additive (Figure 2). A tree to the south was relatively ineffective in producing

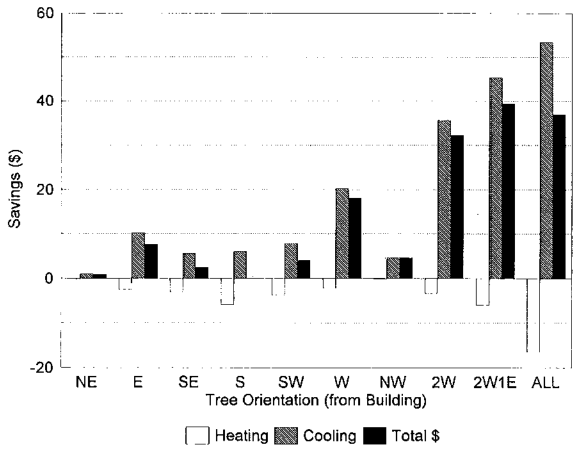

Figure 2. Annual difference (savings are positive) in heating, cooling and total energy use in Sacramento, expressed as a percentage of unshaded base case energy use (kWh), for single trees located at cardinal (E, S, W) and inter–cardinal (NE, SE, SW, NW) points around an east–west oriented building. Results also given for two west trees (2W), one east and two west trees (2W1E), and seven trees located in all directions except north (ALL).

cooling savings since the moderately–sized tree used (24 ft high) provided little shade at midday when the sun is high in the sky.

Annual (kWh) cooling savings were partially offset by usually small but negative impacts of shade that result from reduced winter solar access increasing heating requirements. Increased heating demand was most pronounced for trees on the south; one tree to the south had about the same negative effect as one east and two west trees combined (Figure 2). Cooling savings for trees to the south were offset by increases in annual heating load. In cooler climates especially (e.g. Santa Rosa and Sunnyvale, climate zones 2 and 4, and as reported by Thayer and Maeda [9]), increases in annual heating load can be larger than cooling savings for trees to the south and southeast. This could result in increased total space conditioning costs, depending on the relative costs of cooling compared to heating.

Solar obstruction during the heating season by trees to the south and east can be reduced by selecting "solar friendly" species such as redbud (Cer*cis occidentalis*), green ash (*Fraxinus pennsylvanica*), and honey locust (*Gleditsia triacanthos*) that have open crowns during the leaf– off period, drop their leaves early in the fall, and leaf out in late spring. In addition, taller trees with greater bole heights placed close to buildings will increase summer shading at high sun angles, and increase winter solar access underneath the crown [7].

Peak capacity savings (kW) from simulated shade were found for trees positioned to the west, southwest and northwest, as illustrated for Sacramento (Figure 3). Shade from a single tree positioned on the west side of a house reduced peak demand by 9 percent in Sacramento. Addition of a second tree increased the savings to a total of 17 percent. Savings were approximately additive since shade from multiple tree combinations did not overlap. Southwest and northwest trees had smaller effects, which is partially a function of the time at which peak savings were computed (Table 1). Southwest shade would become somewhat more important for earlier peak times; northwest for later peaks. Savings for seven trees (ALL) was less than for homes with two west trees since in the former only one tree was located directly opposite the west wall.

Effects of climate zone and insulation. Annual percentage savings for cooling (kWh) were larger in cooler climates. Two 15 year old trees located to the west and one to the east of the energy efficient building saved 40 to 50 percent of annual cooling energy in cooler climates (climate zones 2, 4 and 7). The same configuration resulted in 10 to 20 percent savings in hotter regions (climate zones 13, 14 and 15)(Table 1). This result reflects the fact that solar thermal gains constitute a larger proportion of total building heat gain where air temperatures are lower. Conversely, the actual amount of cooling energy saved (kWh) is larger in warmer climates despite the larger percentage savings in cooler locales, due to the larger total cooling loads experienced there (Table 1). Approximate savings ranged from 200 kWh (base case of 400 kWh) for climate zone 7 to 600 kWh (base case of 3,000 to 6,000 kWh) for zones 13, 14 and 15.

Relative annual air conditioning savings were two to three times greater for energy efficient compared to uninsulated buildings with the same

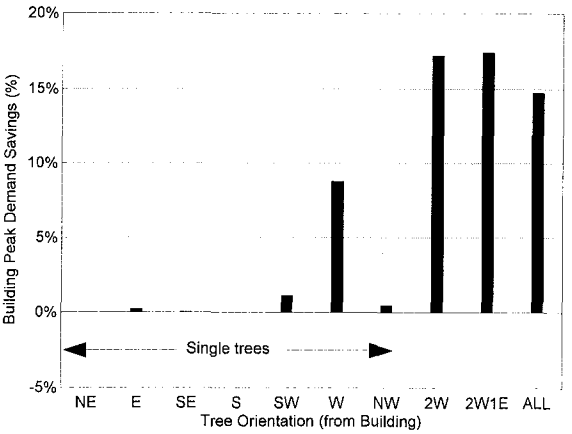

Figure 3. Peak demand savings expressed as a percentage of unshaded base case demand (kW) for tree locations in Figure 2.

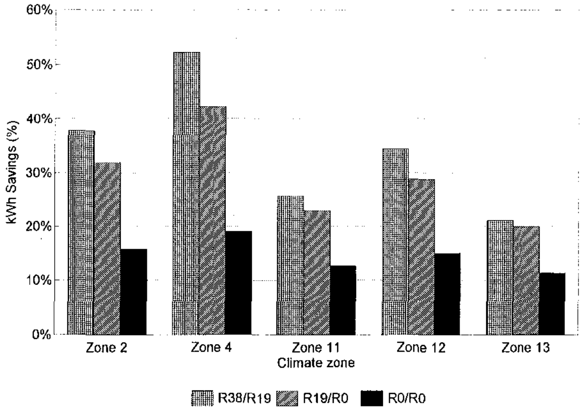

Figure 4. Annual cooling energy savings expressed as a percentage of the unshaded base case for three trees (two to the west and one to the east) around an east–west oriented building for energy–efficient, attic insulated, and uninsulated homes in five California climate zones.

amount of shading (Figure 4). For insulated structures, our simulations showed that conduction gain through walls and ceilings was substantially reduced compared to uninsulated houses. Solar thermal gain through windows remains the same, becoming a larger proportion of overall heat gain in the insulated building. For three trees, two west and one east, savings ranged from 300 to 600 kWh for energy efficient buildings, and from 800 to 1,100 kWh for uninsulated buildings, with larger savings in warmer climates. So, relative energy savings (per cent of kWh) are greater for the energy efficient building; conversely, absolute savings (kWh) are greater for the uninsulated structure.

Building peak demand occurred between 1300 and 1600 hours, depending on climate zone, with later times associated with greater cooling loads (Table 1). Peak savings ranged from approximately 0.2 to 0.7 kW (7 to 23 percent). Climate zone 8 (El Toro) had exceptionally low savings due to the relatively early time of building peak (1300 hours), when there was little shade from trees located to east and west. Here, south or southwest shade (not simulated here for this climate zone) would probably have been more effective than west shade in producing cooling savings, as discussed earlier.

In–leaf shading coefficient and tree form also influence the amount of building surface area shaded and therefore air–conditioning savings [7]. When selecting trees to maximize shade, tree form may be more important than shading coefficient. For example, crown diameters of mature tree species can range from 10 to 50 feet, but summer shading coefficients usually range from 10 to 40 percent (i.e., 60 to 90 percent of solar radiation is blocked). A tall, narrow tree with a dense crown could produce less shade than a broad spreading, open crowned tree in the same location (McPherson [13,16] gives more information on shading coefficients, foliation periods, and other traits of different tree species).

Discussion

Effects of tree placement, numbers, and size (e.g. age) on simulated residential space conditioning energy use have been described for energy efficient, attic insulated and uninsulated houses in 11 California climate zones. Trees shading a west exposure were found to produce the largest annual (kWh) and peak (kW) energy savings for all climate zones and insulation levels considered. Next largest savings were found for southwest (annual and peak) and east (annual only) locations. Three mature trees (two on the west, one on the east side) reduced annual energy use for cooling 10 to 50 percent (200 to 600 kWh, $30 to $110) and peak electrical use up to 23 percent (0.7 kW) for the energy efficient home, depending on climate zone. Trees planted to south and southeast are advantageous for cooling, but increased heating loads due to reduced solar thermal gains in winter may substantially reduce or eliminate any savings from cooling load reduction. Trees to the northwest may reduce peak load; those to the north and northeast of a structure have minimal energy impacts in terms of direct shade.

West, southwest and northwest locations had the greatest effect on building peak demand, because trees in these locations are shading the building during the times of greatest demand, 1300 to 1600 hours (Table 1). This time can differ from utility to utility and between the system as a whole and individual buildings. For a situation with an earlier peak, generally the case if system rather than building peak demand is of interest, shade from southwest or south trees may become more important relative to west trees, since they would provide shade earlier in the day.

While two trees on the west and one on the east provided greatest overall annual (kWh) savings in this study, one may question whether the incremental savings associated with addition of a tree to the east (7% for annual cooling, 2% for annual heating and peak cooling) justifies the added expenses involved (e.g., cost of the tree, irrigation, pruning, litter cleanup). The answer depends upon the range of benefits, and also costs, considered. In a study of cost effectiveness of urban trees in Chicago, McPherson [15] has shown that when the benefits of cooling of the air by evaporation and wind shielding effects are incorporated, as well as costs of planting and initial tree care, benefits derived from single shade trees can outweigh their costs. More comprehensive estimates which consider a wider range of benefits (e.g., including carbon storage, runoff avoidance, air quality improvement, etc.) and costs indicate that multiple trees can produce net benefits in certain markets [16].

Results are considered conservative because they do not include possible energy savings due to local modification of air temperature via evapotranspirational (ET) cooling or wind speed reduction by the wind shielding effect of trees. It is estimated that ET cooling produces savings of approximately the same order of magnitude as direct shade [11,14]. Wind shielding primarily effects heating, resulting in savings about 1 percent per tree [8,20].

The main determining factor for climate zone classification is average air temperature, because it is good indicator of solar radiation, cloud cover and wind regime [12], which all affect building space conditioning load. Based on this observation, we performed simple regression analysis that showed annual cooling savings (kWh) from three trees were correlated (squared multiple correlation r2 = 0.74) with maximum average monthly air temperatures occurring in July or August (Table 2). Correlation with cooling degree days was somewhat smaller ($r^2 = 0.61$). This result indicates potential for the generalization of the findings in this paper to other cooling dominated climates.

Recommendations

The following recommendations are made as a basis for siting trees in relation to buildings to maximize air conditioning energy and capacity savings from direct shade. With careful planning, proper planting and regular care, shade trees can save energy dollars and provide many other benefits to enjoy.

1. A single tree should be located to provide maximum shade to west or southwest exterior window(s). Alternate choices are east and northwest, and where solar access isn't a consideration, southeast and south.
2. The largest windows without existing shading devices, with the preferred orientations listed above, should be the first choice for shading. For windows with shading devices, those with darker colors benefit most from shading.
3. Additional trees should be located to as to shade remaining windows on the west and southwest sides first, followed by the east side, and then the alternate locations listed above.
4. Shade tends to diminish as building–to–tree distance increases [23]. Trees should be planted so that at maturity the edge of the canopy is very close to the building wall, consistent with other restraints, such as access and fire safety considerations.
5. Planting tall trees at a distance from the south

Table 2. Average monthly and annual air temperature by climate zone (°F).

Month	Climate zone										
	2	4	7	8	9	10	11	12	13	14	15
Jan	45.1	48.7	56.8	54.7	55.4	53.4	44.6	45.0	47.0	43.0	55.6
Feb	50.0	51.9	56.4	56.1	56.8	55.6	49.7	50.3	52.1	48.3	59.3
Mar	52.8	54.5	57.4	57.6	57.7	56.2	52.9	53.4	55.5	52.4	64.8
Apr	55.5	57.1	59.3	60.6	60.7	59.9	58.0	57.5	62.0	56.9	71.3
May	60.5	61.3	62.2	63.6	64.2	64.5	66.9	64.3	69.7	66.0	78.7
Jun	65.7	65.6	65.4	67.4	68.2	70.1	73.3	69.5	77.6	74.8	87.9
Jul	68.1	67.2	69.1	70.9	73.3	76.3	77.7	72.7	82.1	82.3	92.2
Aug	67.4	68.3	70.0	70.7	72.7	76.3	75.6	71.5	80.2	81.5	91.5
Sep	64.8	66.8	68.9	70.1	71.6	72.9	70.8	68.3	73.8	73.1	85.7
Oct	60.0	61.7	65.8	65.3	66.8	66.2	62.5	61.9	65.2	63.2	75.3
Nov	50.7	53.3	59.9	59.3	58.8	57.9	52.0	52.6	53.3	49.9	61.9
Dec	46.4	49.6	56.4	55.7	55.4	52.6	45.1	45.7	46.6	43.3	55.4
Year	57.3	58.8	62.3	62.7	63.5	63.5	60.8	59.4	63.8	61.2	73.3

wall that result in winter, but not summer, shading should be avoided [23].

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Résumé. Cette étude porte sur une simulation de l'effet de l'ombrage des arbres sur la consommation d'énergie pour la climatisation et le chauffage des résidences. Les arbres ombrageant la façade ouest des résidences sont ceux qui produisent les plus grandes économies d'énergie, autant sur une base annuelle que lors de conditions de températures extrêmes, et cela sous tous les climats, quelque soit le degré d'isolation considéré. Au second rang pour les économies d'énergie viennent les résidences où les arbres sont localisés sur la façade sud-ouest (économies sur une base annuelle et lors de conditions extrêmes de température) et ceux localisés sur la façade est (économies sur une base annuelle seulement). La présence de trois arbres – deux sur la façade ouest et un sur celle de l'est – diminue la consommation annuelle d'énergie aux fins de climatisation de 10 à 50% et lors des périodes de consommation extrême d'électricité par un facteur de 23%. À l'exception des zones climatiques où les besoins en climatisation sont moins élevés, les réductions de consommation au chapitre de la climatisation se sont toujours avérées être plus importantes que celles provoquées par l'augmentation de la consommation en chauffage en raison de la présence d'arbres sur la façade sud des bâtiments. Les économies au chapitre de la climatisation, autant sur une base annuelle que lors de conditions extrêmes de température, sont plus élevées sous des climats plus chauds et lorsque les bâtiments sont isolés; les économies sont plus importantes sous des climats plus tempérés et pour des édifices à haut rendement énergétique. Des recommandations générales sont faites en regard de la localisation des arbres pour maximiser les économies d'énergie.

Zusammenfassung. In dieser Studie wird der Einfluß der Beschattung von Gebäuden durch Bäume auf den Energieverbrauch von Klimaanlagen und Heizungen simuliert. Bäume, die die westliche Seite eines Gebäudes beschatten, produzieren die größten Energieeinsparungen, sowohl jährlich betrachtet als auch von der Höhe der Amplitude. Das betrifft alle Klimazonen und Standorte. Die zweitgrößten Einsparungen werden an südwestlichen und östlichen Standorten gefunden. Drei Bäume (zwei im Westen, einer im Osten) reduzieren den jährlichen Energieverbrauch für Klimatisierung um 10-20% und den elektrischen Verbrauch um 23%. Außer in Klimaten mit geringen Anforderungen an Klimaanlagen waren die Reduktion der Kühlungsanforderungen in Verbindung mit Schatten von südwestseitig stehenden Bäumen immer größer als der Anstieg der Heizungsanforderungen. Die Einsparungen der Kilmaanlage, sowohl jährlich als auch von der Höhe der Amplitude, waren in warmen Klimaten und nicht isolierten Gebäuden höher; die Einsparungen in kühleren Klimaten und bei Gebäuden mit effizienterer Energieausnutzung waren ebenfalls größber. Es werden hier allgemeine Hinweise gegeben, um die Pflanzorte von Bäumen um Gebäude herum zu bestimmen und die maximale Energieeinsparung zu erhalten.