Index

A
Abbot, C. G., 6, 44, 45
Abbot silver disc pyrheliometer, 45
Abdel-Khalik, S. I., 278, 398–400, 527–529
Abetti, G., 354
Absorbers (concentrating collectors), 322, 323
cylindrical absorber arrays, 323–337
tubular, with CPC reflectors, 344
Absorptance:
cover systems, 206–211
opaque materials, 174–176
angular dependence of, 196–197
broadband, 182–183
calculation of, 183–186
of cavity receivers, 197–198
measurement of, 186–188
relationship of reflectance and, 181–182
passive room-window combinations, 554
Absorption, 60
by blackbodies, 139
in CPC collectors, 345–349
through glazing, 206, 219–223
monthly average, 223–229
of photovoltaic cells, 231–234
of rooms, 229–230
Absorption coolers, 576–578
applications of, 591
continuous, 576–577
intermittent, 577–578
operating experience with, 589–591
refrigeration, 575
simulation air conditioning study, 585–588
type of, 578–584
types of, 576–578
Acceptance angle (nonimaging concentrators), 338
Actinometers, 44, 46, 47
Active collection–passive storage (ACPS) systems, 563–565
costs of, 572
design methods for, 736–742
Active heating. See also Water heating for building heating, 505–541
for air systems, 507–509, 513–517
architectural considerations, 539–541
auxiliary energy during off-peak periods, 533–535
CSU House II air system, 513–517
CSU House III flat-plate liquid system, 511–513
economics of, 536–539
history of, 506–507
liquid systems, 509–511
modes of operation, 510–511
overheating, 535
parametric study of, 517–521
phase change storage systems, 527–529
seasonal energy storage systems, 530–533
solar energy–heat pump systems, 521–527
design methods for, 668–669
f-chart method, 668–690
for air systems, 679–683
for liquid systems, 673–679
and parallel solar energy–heat pump systems, 686–690
results of, 685–686
for service water heating, 683–684
utilizability methods, 692–709
daily utilisability, 696–709
hourly utilisability, 693–696
Advances in Solar Energy, 745
AEIC-EEI Heat Pump Committee, 622
Afeef, M., 634
Africa, weather data for, 865
Agnihotri, O. P., 173, 188n.8
AIA Research Corporation, 545, 566, 570
Air heating:
building heating, 507–511, 513–517
active collection–passive storage systems, 563–564
CSU House II, 513–517
CSU House III, 511–513
energy storage in, 375
f-chart method for, 679–683
flat-plate collectors, 312–313
flow rate data corrections, 306–307
thermal performance, 291, 299–300
for industrial processes, 604
open-circuit, 607–611
recirculating, 611–613
Air mass, 9–10

COPYRIGHTED MATERIAL
Index

Ajami, F., 398
Akbarzadeh, A., 558
Alaska, weather data for, 866
ALCC (annualized life-cycle cost), 453
ALCS (annualized life-cycle savings), 453
Alexander, G., 622–624
Allen, R. W., 580
Altamount Pass, California, 777
American Society of Testing and Materials, 6
American Solar Energy Society, 544–545, 601
American Wind Energy Association, 775
Ammonia-water coolers, 580, 581
Anand, D. K., 665
Anderson, B., 546
Anderson, E. E., 30
Anderson, J. V., 686, 688, 689
Anderson, L. B., 539
Anderson, R., 571
Andrassy, S., 503
Angle(s) of incidence, 15, 202–203
defined, 13
and transmittance-absorptance product, 214–215
Angles of refraction, 202–203
Ångström, K., 45
Ångström compensating pyrheliometer, 45–46
Angular dependence:
and radiation transmission through glazing, 214–215
of solar absorbance, 196–197
Angular-hemispherical reflectance, 178, 186
Anisotropic sky, 91–97
Anisotropy index, 92
Annals of the International Geophysical Year (IGY), 49, 51
Annual cash flow (savings), 466–467
Annualized life-cycle cost (ALCC), 453
Annualized life-cycle savings (ALCS), 453
Antifreeze loop/heat exchanger systems, 424, 480, 481, 484
Aperture:
concentrating collectors, 323, 324
solar, 713, 714
Aquifer energy storage, 396
Architectural considerations:
with active heating, 539–541
overhangs and wingwalls, 34–35
with passive heating, 544
Area concentration ratio, 325
Argentina, weather data for, 869
Arizona, weather data for, 866
Arnold, J. N., 154, 155, 157
Arny, M. D., 410
ASHRAE, 290, 409, 415, 418, 622, 687, 728
ASHRAE Cooling and Heating Load Calculation Manual, 412
ASHRAE Handbook of Fundamentals, 412, 416, 546, 576
ASHRAE standard atmosphere, 70–71
Asia, weather data for, 865
ASME Journal of Solar Energy Engineering, 621
Aspliden, C. I., 779
Atacama Desert, Chile, solar ponds in, 646
Atmospheric attenuation, available solar radiation and, 43, 59–64
Attwater, C. R., 530
Augmentation of available radiation, 97–101
Australia, weather data for, 869
Auxiliary energy, 409
for building heating, 510, 546
for direct-gain systems, 555–557
and economics of passive heating, 572
electric, for off-peak active heating systems, 533–535
with vented vs. unvented storage walls, 558
for water heating, 479, 481, 486–488
Available solar radiation, 43–133
atmospheric attenuation, 43, 59–64
augmentation of, 97–101
beam and diffuse components of:
daily radiation, 77–79
hourly radiation, 74–77
monthly radiation, 79–81
data on, 54–59
definitions related to, 43–44
distribution of clear/cloudy days/hours, 71–74
estimation of:
average radiation, 64–68
clear-sky radiation, 68–71
hourly radiation, from daily data, 81–84
instruments for measuring:
duration of sunshine, 53
pyranometers, 48–53
pyrheliometers and pyrheliometric scales, 44–48
moving surfaces, beam radiation on, 101–103
and receiving surface orientation, 112–114
on sloped surfaces, 84–89
anisotropic sky, 91–97
average radiation: isotropic sky, 103–106
average radiation: KT method, 107–112
isotropic sky, 89–90, 103–106
utilizability, 115–118
daily, 126–132
generalized, 118–126
Average solar radiation:
estimation of, 64–68
isotropic sky, 103–106
KT method, 107–112
monthly absorbed, 223–229
monthly mean daily radiation, 37–40

B
Bacon, F. T., 401
Baer, S., 527
Balcomb, J. D., 392, 413, 450, 558, 561, 571, 669, 712, 714–721
Balcomb house (New Mexico), 566, 568–569
Bankston, C., 530, 532, 533
Bankston, C. A., 394, 396
Bannister, J. W., 77
Bannerot, R. B., 101
Bennett, I., 67
Benn, A. C., 192
Benseman, R. F., 81
Berdahl, P., 148
Biancardi, R., 597
Bin method, 687–690
Blackbodies, 139–140
radiation tables for, 142–144
total energy emitted by, 141–142
wavelengths of emissions from, 140–141, 188
Blinn, J. C., 581, 583
Bliss, R. W., 148, 275, 506, 600, 622
Bloch, M. R., 614
Boggs, R. A., 192
Bouguer’s law, 206
Bowen, I. S., 646
Brandon, M. J., 212, 347, 468, 471
Braun, J., 394, 530–532
Braun, J. E., 20, 491
Bridgers, F. H., 622
Brinkworth, B., 424
Broadband absorption, 182–183
Broadband emittance, 182–183
Brunstrom, C., 395
Bryant, H. C., 634
Buchberg, H., 154, 654
Buckles, W. E., 488, 683
Buehl, W. M., 277
Buhrman, R. A., 192
Building heating:
active, 505–541
air systems, 507–509, 513–517
architectural considerations, 539–541
auxiliary electric energy during off-peak periods, 533–535
CSU House II air system, 513–517

Beckman, D. M., 597
Belgium, weather data for, 865
Bell, R., 193
Bellani spherical distillation pyranometer, 53
Belton, G., 398
Bendi, P., 74, 361, 669
Benford, F., 12
Bennet, I., 67
Benning, A. C., 192
Benseman, R. F., 81
Berdahl, P., 148
Biancardi, R., 597
Bin method, 687–690
Blackbodies, 139–140
radiation tables for, 142–144
total energy emitted by, 141–142
wavelengths of emissions from, 140–141, 188
Blinn, J. C., 581, 583
Bliss, R. W., 148, 275, 506, 600, 622
Bloch, M. R., 614
Blytas, G. C., 577
Bock, J. E., 12
Bode, H., 402
Boeing, 368
Boiling protection (water heating), 483–486
Bond, J. A., 597
Bonds, L. P., 614
Bouguer’s law, 206
Bowen, I. S., 646
Brandemuehl, M. J., 212, 347, 468, 471
Braun, J., 394, 530–532
Braun, J. E., 20, 491
Bridgers, F. H., 622
Brinkworth, B., 424
Broadband absorptance, 182–183
Broadband emittance, 182–183
Brunstrom, C., 395
Brun, D., 148
Bryant, H. C., 634
Buchberg, H., 154, 654
Buckles, W. E., 488, 683
Buehl, W. M., 277
Buhrman, R. A., 192
Building heating:
active, 505–541
air systems, 507–509, 513–517
architectural considerations, 539–541
auxiliary electric energy during off-peak periods, 533–535
CSU House II air system, 513–517

Index  889
Building heating (continued)
   CSU House III flat-plate liquid system, 511–513
economics of, 536–539
   history of, 506–507
   liquid systems, 509–511
   modes of operation, 510–511
   overheating of, 535
   parametric study of, 517–521
   phase change storage systems, 527–529
   seasonal energy storage systems, 530–533
   solar energy-heat pump systems, 521–527
   combined solar heating and cooling systems, 584–585
   CombiSys space heating subsystem, xx
degree-day method, 412–415
   hybrid systems, 563–565, 736–743
   active collection with passive storage, 736–742
   both passive and full active heating systems, 742–743
   passive, 544–563, 711–735
   applications of, 565–570
   approaches to, 711–712
   collector-storage walls and roofs, 557–561
   comfort criteria, 546
   concepts of, 545–546
   costs and economics of, 571–573
direct gain systems, 229–230, 552–557
   heat distribution in, 571
   movable insulation and controls, 546–547
   shading, 547–552
   solar-load ratio method, 712–721
   and storage media performance, 373
   sunspaces, 561–563
   unutilizability design method, 721–735
   simulation of, xix–xxiv
Building loss coefficients, 415–417
Building thermal capacitance, 417
Butso, K. D., 413
Butz, L. W., 581, 654

C
   Cabot, Godfrey L., 506
   California, weather data for, 866
   Campbell Soup Co., 614
   Campbell-Stokes sunshine recorder, 53
   Canada, J. R., 447
   Canada, weather data for, 866

Canadian Climate Normals, 863
   Caracol, 646
   Caribbean, weather data for, 866
   Carlsson, B., 398
   Carvalho, M. J., 490
   Casamajor, A. B., 617
   Casella, 50
   Cavity receivers:
      absorptance of, 197–198
      with paraboloidal concentrators, 367
   CEC, see Commission of the European Communities
   Cell temperature (PV systems), 757–759
   Central-receiver collectors, 368–369
   Central-receiver systems, 628–629
   Chant, R. E., 77, 79, 132
   Charters, W. W. S., 154, 161, 392
   Chemical energy storage, 400–402
   Chiam, H. F., 101
   Chinnappa, J. V. C., 577
   Chiou, J. P., 280
   Choi, H., 160
   Choudhury, N. K. D, 77, 79
   Chow, S. P., 336, 337
   Chromosphere (sun), 5
   Chung, R., 576
   CHX, see Collector heat exchanger
   Cinquenami, V., 863
   Circumsolar diffuse radiation, 85
   Circumsolar ratio (CSR), 91
   Clark, D. R., 125, 765, 767, 768, 770
   Clear/cloudy days/hours, distribution of, 71–74
   Clearness indexes, 71–72
   Clear-sky radiation, estimation of, 68–71
   Close, D., 599
   Close, D. J., 192, 193, 195, 310, 429, 452, 481, 483, 491, 492, 506, 611, 653–654
   Coatings, high-absorptance, 192–193
   CoDoPro (Collector Design Program), 313
   Coefficient of performance (COP), 516, 522, 580
   Colbeck, L., 634
   Collares-Pereira, M., 77, 78n.12, 79, 80n.13, 81, 115, 692, 696
   Collection efficiency, 238
   Collectors. See also individual types and specific components
   in CombiSys, xix–xx, 798
   ICS water heaters, 494–496
   loads and outputs of, 373–375
   solar-mechanical systems, 621–622
Index

and storage unit design, 375
tracking surface angles for, 20–23
windows as, 545
Collector Design Program (CoDoPro), 313
Collector efficiency factor:
flat-plate collectors, 257–261
and liquid heater design, 275–277
Collector flow factor, flat-plate collectors, 263–266
Collector heat exchanger (CHX):
in CombiSys, xx
defined, 423
in liquid-based heating systems, 509–510
Collector heat exchanger factor, 424–425
Collector heat removal factor, flat-plate collectors, 262–266
Collector-storage roofs:
costs of, 571
passive building heating systems, 557–561
Collector-storage walls, 392–394
costs of, 571–572
defined, 545
design parameters for, 715
loss control with, 546
passive building heating systems, 557–561
unutilizability design method, 727–735
Collector-tank heat exchanger, in CombiSys, 798
Collier, R. K., 592
Colorado, weather data for, 866
Colorado State University (CSU):
CSU House I cooling, 582, 663
CSU House II air system, 513–517, 540, 599–600, 685
CSU House II flat-plate liquid system, 511–513, 589–591
Combined solar heating and cooling, 584–585
CombiSys, xix
collector heat exchanger in, xx
collector in, xix–xx
domestic hot water subsystem in, xx
finding/installing, 797–798
on-line plots, xxiii
output from, xxiii–xxiv
solar storage tank in, xx
space heating subsystem in, xx
weather data in, xix
COMBISYS.OUT file, xxiii–xxiv
Comfort criteria, for passive building heating systems, 546
Commission of the European Communities (CEC), 55, 565, 570
Commonwealth Scientific and Industrial Research Organization (CSIRO), 493
Component models (system thermal calculations), 422–423
Compound parabolic concentrators (CPCs):
optical characteristics of, 338–344
orientation and absorbed energy for, 345–349
performance of, 332–334, 349–351
Concentrating collectors, 322–370
central-receiver collectors, 368–369
compound parabolic concentrators:
optical characteristics of, 338–344
orientation and absorbed energy for, 345–349
performance of, 332–334, 349–351
centration ratio, 325–327
configurations for, 323–325
cylindrical absorber arrays, 335–337
incidence angle modifiers and energy balances, 361–367
linear imaging concentrators:
geometry of, 351–354
imperfect, imaged from, 359–361
perfectly-oriented, images formed by, 354–359
nonimaging concentrators, 337–344
optical performance of, 334–335
paraboloidal concentrators, 367–368
practical considerations for, 369–370
ray-trace methods for evaluating, 361
thermal performance of, 327–334
types of, 322
Concentration ratio:
concentrating collectors, 325–327, 368
defined, 322
variation in, 322
Concentrators (in concentrating collectors), 322, 323
Concentric cylinders, natural convection between, 153–154
Connelly, M., 669
Continuous absorption cycles (cooling), 576–577
Controls:
collector-storage walls, 558
passive heating systems, 547, 558
photovoltaic systems, 763
system thermal calculations, 429–431
Control function (CPC collectors), 346
Convective zone (sun), 4
Convectors, photovoltaic, 746–747
Cook, F. W., 81
Cooling, 575–601
applications of, 591
operating experience with, 589–591
refrigeration, 575
simulation air conditioning study, 585–588
type of, 578–584
types of, 576–578
combined solar heating and cooling, 584–585
desiccant cooling, 592–596
passive, 601
solar-mechanical, 596–599
solar-related methods, 599–601
and water heating, 497
COP, see Coefficient of performance
Costs of solar process systems, 447–450.
See also Economic evaluation
active heating systems, 536–537
flat-plate collector installation, 312
passive building heating systems, 571–573
Coulson, K. L., 9, 44, 48, 51, 52, 84–85, 92
Cover systems. See also Glazing, radiation
transmission through
flat-plate collectors, 268–271, 278, 311
optical properties of, 206–211
refractive index of materials, 205–206
spectral dependence of transmittance, 215–218
for swimming pools, 502
CPCs, see Compound parabolic concentrators
Crawford, E., 159, 161, 163
Critical radiation level:
defined, 115
for flat-plate collectors, 266–267
CSIRO (Commonwealth Scientific and
Industrial Research Organization), 493
CSR (circumsolar ratio), 91
CSU, see Colorado State University
Cummings, N. W., 647
Cuomo, J. J., 193
Cylindrical absorber arrays, for concentrating
collectors, 335–337
Czapek, E. L., 546
Czarnecki, J. T., 114, 497
D
Daily clearness index, 71
Daily utilizability, 126–132, 696–699
defined, 128–129
f-chart method, 699–709
Dulénbäck, J-O., 490, 532
Daniels, F., 577
Davey, E. T., 308, 309
Davies, J. A., 91
Davis, M. W., 758
Daylighting, 544
Declination, 12
Deflation, 455
De Garmo, E. P., 447
Degelman, L. O., 665
Degree-day method:
cooling, 418
for country weather data, 863
space heating, 412–415
DeJong, B., 56
Delyannis, E., 640
Denmark, wind energy in, 775
Denver bus maintenance facility, 609–611
Denver House, 512, 540
Desiccant cooling, 592–596
Design variables, economics of systems and,
450–452
Design year, 664, 665
DeSoto, W., 231, 753
Dewar collectors, 335–336
DeWinter, F., 424, 503
DeWitt, D. P., 153, 159
DHW, see Domestic hot water subsystem
Dickenson, W. W., 617
Dietz, A. G. H., 202, 216, 271, 546
Diffuse radiation:
circumsolar, 85
and collector performance prediction,
296–297
daily, 77–79
defined, 10
hourly, 74–77
monthly, 79–81
ratio on tilted surfaces to horizontal surfaces,
23
transmittance for, 211–213
(continued)

Diffuse reflection, 177
Diffuse surfaces, 146
Direct-coupled systems, load characteristics for, 759–763
Direct gain, 545
Direct-gain systems:
- for building heating, 552–557
  - absorbance of rooms, 229–230
  - unutilizability design method, 721–727
- combined with ACPS, 565
- design parameters for, 715
- loss control in, 546
- problems associated with, 570
Directional absorbance, 174
Directional emittance, 174
Directional selectivity, 193–194
Directory of SRCC Certified Solar Collector Ratings, 299n.18, 300
Direct solar drying, 647
Direct solar radiation, see Beam radiation
Discounting, 454–456
Dispersion angle (linear imaging concentrators), 359
Distillation, 640–645
Doldrums, 778
Domestic hot water subsystem (DHW), See also Water heating
- in CombiSys xx, 798
  - f-chart method for, 669–672, 685
  - low-flow systems, 479
- “Double-U” design method, see
  - Unutilizability design method (passive systems)
Drain-back (drain-down) systems, 484, 510–513
Drain-out systems, 484
Dunlavy, A. J., 6
Dual-source solar energy–heat pump systems, 523, 524
Duct loss factors, 423, 426–429
Duffie, J. A., 77, 79, 239, 327, 361, 576, 686
Duffie, N. A., 611
Duncan, C. H., 6
Dunkle, R. V., 142, 166, 167, 192, 294–295, 308, 309, 592, 593, 642, 643
Dunn, J. R., 393
Duration of sunshine, instruments for measuring, 53
Dust, flat-plate collector performance and, 271–272

E
Earth tempering, 601
Ellis, J. M., 794
Electromagnetic spectrum, 138–139
Ellul, W. H. J., 166
El Paso, Texas, solar pond in, 639–640
Elshernbin, S. M., 158
Emittance, 174–176
- by blackbodies, 140
- broadband, 182–183
- calculation of, 183–186
- measurement of, 186–188
- relationship of reflectance and, 181–182
ENERGIE program, 711

Index 893

(continued)
Energy balances:
- concentrating collectors, 361–367
- direct-gain systems, 555
- flat-plate collectors, 237–238
- heat pump–solar energy heating system, 524
  with hybrid heating systems, 565
- industrial process heat storage, 605
- and Kirchhoff’s law, 176
- solar ponds, 646
- storage walls, 392
- water storage tanks, 377–378

Energy (product) storage, 373–406
- active collection–passive storage systems, 563
- active systems:
  - liquid systems, 676–679
  - phase change systems, 527–529
  - seasonal systems, 530–533
- architectural considerations for, 541
- battery storage, 402–406
- chemical energy storage, 400–402
- ICS water heaters, 494–496
- for industrial process heat, 605
- packed beds, 165–167, 384–391
- passive building heating systems, 545
- collector-storage walls and roofs, 557–561, 727–735
- sunspaces, 229–230, 561–563
- phase change energy storage, 396–400
- photovoltaic systems, 763
- seasonal storage, 394–396
- solar process loads and collector outputs, 373–375
- in solar process systems, 375–376
- solar storage tank, xx
- storage walls, 392–394
- stratification in storage tanks, 379–384
- water heating, 494–496
- water storage, 376–379

Engineering Equation Solver (EES), 240
Eppley normal-incidence pyrheliometer (NIP), 46
Eppley precision spectral pyranometer (PSP), 48, 49
Eppley pyranometer, 48, 49, 51, 52
Equilibrium (stagnation) temperatures, 310
Erb, D. G., 75, 76, 78, 80, 413, 418
ERDA Solar Workshop, 629
Etter, D. E., 639
Europe, weather data for, 865–866

European Solar Radiation Atlas, 55, 109, 863

European Union, 290
Evans, B. L., 565, 736, 738–740, 742, 743
Evans, D. L., 115, 354–357, 360, 765, 767, 768
Evaporation, 646–647
Evaporative processes:
- direct solar drying, 647
- distillation, 640–645
- evaporation, 646–647
- solar ponds, 635–640
- applications of, 639–640
- salt-gradient, 635–637
- theory of, 637–639

Experiments, simulations and, 655, 663
Extraterrestrial radiation. See also Solar radiation
- on horizontal surfaces, 37–41
- spectral distribution of, 6–8
- variation of, 8–9
- wavelengths of, 188

Fanger, P. O., 546
Fanney, A. H., 231, 232, 685, 686, 745
Farber, E. A., 70–71
Farber, J., 503
f-chart method, 668–690
- for air systems, 679–683
- for liquid systems, 673–679
- and parallel solar energy–heat pump systems, 686–690
- results of, 685–686
- for service water heating, 683–684
Fender, D. A., 393
Flat parallel plates, natural convection between, 149–153
Flat-plate collectors, 236–319
- air heaters, 280–287
- characterizing, 288–289
- collector heat removal factor, 262–266
- critical radiation level for, 266–267
- CSU House III flat-plate liquid system, 511–513
- described, 236–237
- dust and shading effects, 271–272
- effective transmittance-absorptance product, 268–271
- energy balance equation for, 237–238
  with flat covers vs. cylindrical covers, 278
  flow distribution in, 308–309
  flow factor, 263–266
  heat capacity effects in, 272–275
liquid heater plate geometries, 275–280
mean fluid temperature, 267
mean plate temperature, 267–268
overall heat loss coefficient for, 240–254
performance measurements for, 287–288
practical considerations for, 310–313
in situ performance, 309–310
temperature distributions, 238–240
collector efficiency factor, 257–261
in flow direction, 261–262
between tubes, 254–261
test data for, 289, 299–302
conversion of, 302–305
flow rate corrections, 305–307
tests for, 289–298
basic method of testing, 290
efficiency tests, 290–295
general test procedure, 291
incident angle tests, 290, 295–297
time constant, 290, 297–298
tube, 254–251, 275
Flow direction:
in liquid heaters, 277
temperature distributions in, 261–262
Flow distribution, in flat-plate collectors, 308–309
Flow rates:
active air systems, 680–681
corrections of flat-plate collector test data, 305–307
low-flow hot-water systems, 479
Flux concentration ratio, 325
Forced-circulation systems (water heating), 479–481, 488–499
Forristall, R., 327, 363
Foskett, L. W., 53
Foster, N. B., 53
Foster sunshine switch, 53
FPL Energy, 624
Francey, J. L., 419
Freeman, T. L., 525, 526
Freeze protection (water heating), 483–484
Freris, L. L., 780, 796
Fresnel reflectors, 324
Fritz, S., 60, 62
Frohlich, C., 6, 9
Fuel expense, 448–449, 538
Fuess, 50
Fujii, I., 401
Funaro, G., 565
Furbo, S., 481

G
Garg, H. P., 10, 271, 491, 653
Gari, H. N., 379, 380
Gaul, H., 362
Generalized utilizability, 118–126
Generators, photovoltaic, 761–764
characteristics and models, 747–757
high-flux generators, 770–771
Geological Survey, 646
Georgia, weather data for, 866
Germany, weather data for, 865
Gier, J. T., 186, 192
Gild Bend pumping system, 622–624
Gillett, W. B., 289n.13, 291, 298, 745
Gilon, Y., 625, 626
Gilroy Foods, 615, 616
Glass, 202
etched and unetched, 218–219
spectral transmittance of, 215–216
Glazing, radiation transmission through, 202–234
absorption, 206, 219–223
monthly average, 223–229
of photovoltaic cells, 231–234
of rooms, 229–230
and building loss coefficients, 415
for collector-storage walls, 545
optical properties of cover systems, 206–211
and reflection of radiation, 202–206
spectral dependence of transmittance, 215–218
surface layers’ effects on, 218–219
transmittance-absorptance product, 213–215
transmittance for diffuse radiation, 211–213
Global radiation, 10
Golding, P., 419
Gold Kist soybean plant, 607–609
Gordon, J., 763
Gordon, J. M., 493
Govaer, D., 502
Graham, B. J., 615, 616
Grashof number, 149
Grassie, S. L., 101
Gray surfaces, infrared radiation between, 146–147
Greco, C., 566
Grreece, weather data for, 865
Green Bay water heating plant, 615–617
Grid-connected PV systems, 763
Grimmer, C. P., 193
Grimmer, D. P., 101
Groiss pyranometer, 48
Gross reference load, 713
Ground-reflected radiation:
and collector performance prediction, 296–297
thermal energy storage in, 395–396
Ground temperatures, 601
Gruntfest, I., 397
Gueymard, C., 63
Guinn, G. R., 607, 608, 617, 618
Gulachenski, E. M., 764
Gupta, B. K., 173, 188n.8
Gupta, C. L., 491, 653, 654
Gutierrez, G., 487

Heat
damage, 311–312
Hall, B. R., 617, 618
Hall, I. J., 664
Hamid, Y. H., 280
Hamilton, D. C., 98
Harats, Y., 193, 195, 369, 625, 626
Harding, G. L., 193
Harrison, D., 546
Hatch, W. L., 413
Hawley, R. W., 167
Hay, H. R., 560, 600
Hay, J. E., 85, 91
HDKR model, 91–93, 96, 97, 221–222
Heat capacity, of flat-plate collectors, 272–275
Heat distribution, in passive buildings, 571
Heat exchangers:
for active liquid systems, 677–679
antifreeze loop/heat exchanger systems, 424, 480, 481, 484
collector heat exchanger factor, 424–425
effectiveness-NTU calculations for, 168–170
in hot water systems, 481
Heating, see Active heating; Passive heating
Heating loads, in passive building heating systems, 546
Heat loss coefficient, overall, 240–254
Heaton, H. S., 159, 161
Heat pumps:
in active building heating/cooling systems, 521–527, 530
for cooling, 600
in parallel solar energy–heat pump systems, 686–690
Heat transfer, 138–170
blackbodies, 139–140
convection suppression, 154–158
electromagnetic spectrum, 138–139
heat exchangers, 168–170
infrared radiation between gray surfaces, 146–147
internal flow coefficients, 159–163
natural convection:
between flat parallel plates, 149–153
between horizontal concentric cylinders, 153–154
phonon radiation, 139
Planck’s law, 140–141
and pressure drop:
in packed beds, 165–167
in perforated plates, 167–168
radiation flux, 144–146
radiation heat transfer coefficient, 147–149
radiation intensity, 144–146
radiation tables, 142–144
sky radiation, 147–148
Stefan-Boltzmann equation, 141–142
vee-corrugated enclosures, 158
Wien’s displacement law, 140–141
wind convection coefficients, 163–165
Hedstrom, J. C., 669
Hemispherical absorptance, 175–176
Hemispherical-angular reflectance, 178, 186
Hemispherical emittance, 175–176
Hemispherical reflectances, 178–181
Henderson, J. B., 63
Herzog, M. E., 74, 109
Hickey, J. R., 6, 9
High-flux generators (PV systems), 770–771
Hildebrandt, A. F., 368
Hill, J. E., 289, 298–300
Hinterberger, H., 338, 343
Hodgins, J. W., 398
Hoffman, T. W., 398
Hohlraum, 186
Hollands, K. G. T., 74–76, 101, 150, 153, 154, 157, 194, 280, 324, 345n.9, 490, 491
Hollingsworth, F. M., 546
Honeywell, 199
Hooper, F. C., 530
Horizon brightening, 85
Horizontal concentric cylinders, natural convection between, 153–154
Horizontal surfaces:
extraterrestrial radiation on, 37–41
ratio of beam radiation on tilted surfaces to, 23–29
Hottel, H. C., 24n.7, 25, 68, 69, 81, 89, 115, 146, 192, 209, 238, 250, 271, 275, 287, 622, 692
Hot-water loads, 410–412
Hot water systems, see Water heating
Hour angle, 13
Hourly clearness index, 72
Hourly radiation:
  beam and diffuse components of, 74–77
  estimation from daily data, 81–84
Hourly utilizability, 693–696
Howell, J. R., 101, 142, 146, 176, 202, 206, 209
Huget, R. G., 74
Hughes, P. J., 387–389, 533, 534
Hull, D. E., 431
Hull, J. R., 634–638
Huxtable, D. D., 401
Hybrid systems, 736–743
  active collection with passive storage, 563–565, 736–742
  both passive and full active heating systems, 565, 742–743
  concepts related to, 545–546
I
IAMS, see Incidence angle modifiers
Ibáñez, M., 72
Ibele, W. C., 621
ICS (integral collector storage) systems, 494–496
IEA (International Energy Agency), 301, 310
IGY (Annals of the International Geophysical Year), 49, 51
Illinois, weather data for, 866
Imaging collectors, 326. See also Linear imaging concentrators
Incidence angle modifiers (IAMs):
  for concentrating collectors, 334–335, 361–367
defined, 223
  for flat-plate collectors, 289
  for photovoltaic panels, 232
Incidence angle modifier coefficient, 295
Incident angle tests, for flat-plate collectors, 290, 295–297
Income tax savings, 449, 450, 500
Incropera, F. P., 153, 159
India, weather data for, 865
Industrial process heat, 604–619
  air heating:
    open-circuit, 607–611
    recirculating, 611–613
  economics of, 606–607
  integration of energy and processes, 604–605
  mechanical design considerations, 605–606
  water heating:
    once-through, 613–614
    recirculating, 615–617
    shallow-pond, 617–619
Infiltration, 416–417
Infinite-NTU method (packed beds), 388–389
Infinite storage capacity, hypothetical, 722, 737
Inflation, 454–456
Infrared radiation exchange, between gray surfaces, 146–147
Insolation, 10
Instantaneous efficiency, 289
defined, 289
  of flat-plate collectors, 290–295
Insulation:
  with collector-storage wall systems, 558–560
  movable:
    in direct-gain systems, 552–555
    in passive building heating systems, 546–547
    in sunspaces, 563
    and passive heating performance, 719
  transparent, 415–416
Integral collector storage (ICS) systems, 494–496
Intercept factors, 334, 365–366
Interfaces, for solar–conventional industrial process heat, 605–606
Intermittent absorption cooling, 577–578
Internal flow coefficients, 159–163
International Energy Agency (IEA), 301, 310
International Pyrheliometer Comparisons (IPC), 46
International Pyrheliometric Scale 1956, 46
International Solar Energy Society, 601
International System of Units, 861–862
Investments:
  in passive systems, 571
  in solar systems, 447–448
IPC (International Pyrheliometer Comparisons), 46
Iqbal, M., 6, 9, 11, 14, 44, 60–62, 81
Irradiance, 10
Irradiation, 10
Isotropic diffuse model, 89–90
Isotropic sky:
  defined, 85
  radiation on sloped surfaces, 89–90, 103–106
Israeli Dead Sea ponds, 639–640

J
Jaffe et al 1987, 625
James, S. R., 298
Jeffreson, C. P., 389
Jensen, C., 625
Jeys, T. H., 47
Jilar, T., 532
Johnson, F. S., 6
Johnson, T. E., 397, 527
Jones, D. E., 282
Jones, R. E., 35, 547
Jurinak, J. J., 400, 528, 529, 595, 596

K
Kakac, S., 159
Karaki, S., 386, 512–517, 589–591, 599–600
Karman, V. D., 524–525
Kasten, F., 10n.3
Kauffman, K., 397
Kays, W. M., 159, 161, 163, 168, 169, 424
Kearney, D., 193, 195, 369, 625, 626
Kearney, D. W., 625, 626
Kenna, J., 669
Kenna, J. P., 745
Kennard, E. H., 140
Khouzam, K., 759
King, D. L., 231, 232, 748, 758
Kipp & Zonen actinometer, 46, 47
Kirchhoff’s law, 176–177
Kirkpatrick, A. D., 571
Kleinbach, E. M., 384
Klucher, T. M., 91, 92
Knight, K. M., 74, 665
Knudsen, S., 481
Kondratyev, K. Y., 10, 44, 62, 84
Koo, J. M., 313
Kooi, C. F., 634, 637
Kovarik, M., 431
KT method (average radiation), 107–112
Kuharich, R. R., 622
Kuhn, J. K., 382–384, 387
Kunz, S., 664
Kusuda, T., 289
Kutscher, C. F., 167, 285, 287

L
Lamb, J. A., 193
Lambertian surfaces, 146
Lameiro, G., 669
Lampert, C. M., 173, 192, 195
Landis, F., 398
Lane, R., 615
Larsson, M., 395
Laszlo, T. S., 322
Latimer, J. R., 51
Latitude, 12
Lavan, Z., 278, 279, 382
LCC, see Life-cycle cost
LCR, (load collector ratio), 713
LCR, (load collector ratio for the solar aperture), 714
LCS, see Life-cycle savings
Least cost solar energy, 452
Lebens, R. M., 546, 712
Lee, T. K., 635
Leonard, J. A., 363
Lesse, P. F., 431
LI-COR pyranometers, 50, 51
Life-cycle cost (LCC), 452, 454, 475
Life-cycle savings (LCS), 452, 459–463, 475, 538
Lightstone, M. F., 490
Lin, R. J. H., 195
Linear imaging concentrators:
  concentration ratios of, 326
  geometry of, 351–354
  imperfect, imaged from, 359–361
  perfectly-oriented, images formed by, 354–359
  thermal performance, 328–332
Linke-Feussner pyrheliometer, 47
Index

Liquid heating, 313
active collection–passive storage systems, 563
drain-back systems, 484, 510–513
f-chart method for, 673–679
flow rate data corrections, 305–306
freeze protection for, 311
for industrial processes, 604–605
plate geometries for heaters, 275–280
thermal performance of, 291, 299–300
Lithium bromide–water air conditioners, 576–584
Littler, J., 562
Liu, W., 496
Lloyd, J. R., 164
Loads, 409–420
building loss coefficients, 415–417
and building thermal capacitance, 417
and collector outputs, 373–375
cooling, 417–418
defined, 409
direct-coupled photovoltaic systems, 759–763
on direct-gain systems, 555
hot-water, 411–412
in passive cooling, 601
in passive heating systems, 546, 711–712
space heating:
degree-day method, 412–415
swimming pool heating, 418–420
time-dependent, 409–411
Load collector ratio (LCR), 713
Load collector ratio for the solar aperture (LCRs), 714
Load heat exchangers, 510
Local flux concentration ratio, 325
Local mirror radius (linear imaging concentrators), 352
Local winds, 778, 779
Lodwig, E., 592
Loehrke, R. I., 379, 380
Löf, L. G. A., 502
Loterski, J. J., 757
London, A. L., 168, 424
Long-wave radiation:
absorptance and emittance for, 188–189
defined, 43
Lorsch, J. G., 541
Los Alamos National Laboratory, 597, 669
Los Alamos Scientific Laboratory, 711
Lose, P. D., 354
Low-flow hot-water systems:
flow rates in, 479
pumped systems, 490–491
Lutz, D. J., 411
Luz International Limited, 624, 628
Luz power systems (California), 369, 624–628
M
McAdams, W. H., 159, 163–165
McCorquodale, J. A., 166
McDaniels, D. K., 101
McDonald, G. E., 192
MacDonald, T. H., 48
McDonnell-Douglas, 368
McFarland, R. D., 712
McIntire, W. R., 297
McKay, D. C., 85
Mahone, D., 570
Main storage tank (in CombiSys), 798
Manitoba, weather data for, 866
Manwell, J. F., 777, 779, 780, 786, 788, 796
Mar, H. Y. B., 195, 218, 219
Marcus, R. J., 401
Mariner satellite, 6, 8
Marlatt, W. P., 609, 610
Martin, D. C., 192, 193
Martin, M., 148
Martin Marietta, 368
Marvin, W. C., 387, 524, 526
Massachusetts, weather data for, 868
Massachusetts Institute of Technology (MIT), 506, 570
Masters, L. W., 311
Mather, G. R., Jr., 336
Mattox, D. M., 192, 196
Matz, R., 635
Maximum power point trackers (PV systems), 759, 763
Maycock, P. D., 745
Mazria, E., 30, 546, 712
Meader, M., 597
Mead, Egypt, irrigation plant, 621
Mean fluid temperature (flat-plate collectors), 267
Mean plate temperature (flat-plate collectors), 267–268
Mechanical design considerations:
for flat-plate collectors, 311
for industrial process heat, 605–606
MEC (Munters Environmental Control) system, 594–595
Meinel, A. B., 193
Melnikov, G. K., 338
Menicucci, D. F., 770
Mercer, W. E., 161
Messenger, R. A., 745, 752, 763
METEONORM data set, 863
Meteorological (weather) data, 863–869
in CombiSys, xix
for simulations, 663–666
for specific locations, 865–869
in system thermal calculations, 422
Method 5000, 712
Mexico, weather data for, 866
Meyer, B. A., 154–157
Michelson pyrheliometer, 47
Mirror radius (linear imaging concentrators), 352
MIT (Massachusetts Institute of Technology), 506, 570
Mitchell, J. C., 20, 346
Mitchell, J. W., 164, 165, 412, 415, 418, 525, 526, 591, 663, 664, 686
MIT House IV, 506, 510, 540, 685
MIT House V, 527
Modified-Euler method, 657
Moll-Gorczynski pyranometer, 48, 49
Moll-Gorczynski pyrheliometer, 47
Monochromatic angular-hemispherical reflectance, 178–181
Monochromatic directional absorptance, 174, 181
Monochromatic directional emittance, 174, 181
Monochromatic hemispherical absorptance, 175–176
Monochromatic hemispherical-angular reflectance, 179
Monochromatic hemispherical emittance, 175–176
Monthly average clearness index, 71
Monthly mean daily extraterrestrial radiation, 37–40
Monthly radiation:
absorption through glazing, 223–229
beam and diffuse components of, 79–81
monthly mean daily radiation, 37–40
and receiving surface orientation, 112–114
Moon, J. R., 289n.13, 298
Moon, P., 60
Moore, S. W., 192, 288
Moran, W. P., 164
Morgan, W. R., 98
Morrison, C. A., 70–71
Morrison, D. J., 398–400, 527
Morrison, G. L., 491, 493
Morse, R. N., 114, 645
Mouchot, 621
Movable insulation:
in direct-gain systems, 552–555
in passive building heating systems, 546–547
in sunspaces, 563
Moving surfaces, beam radiation on, 101–103
Mullett, L. B., 634
Multi-node approach (storage tanks), 379–382
Mumma, S. A., 524, 526
Mumma, S. D., 387
Munters Environmental Control (MEC) system, 594–595
Murray, W. D., 398
Murty, M. V. R. K., 361
Mutch, J. J., 410, 488
Myer, A., 712
N
National Aeronautics and Space Administration (NASA), 6, 63
National Bureau of Standards (NBS), 289
National Climatic Data Center, 59
National Passive Solar Conferences, 545
National Renewable Energy Laboratory (NREL), 20, 59, 780, 863
National Security and Resources Study Center, 597
National Solar Radiation Data Base (NSRDB), 55, 863
Natural circulation water heaters, see Passive water heaters
Natural convection:
between flat parallel plates, 149–153
between horizontal concentric cylinders, 153–154
NBS (National Bureau of Standards), 289
Index

Neeper, D. A., 280
Nelson, J., 745
Nelson, J. S., 595
Nelson, K. E., 367
Net glazing area, 713
Net load coefficient, 713
Net present worth, 452
Net reference load, 713
Neumann, A., 91
Nevada, weather data for, 868
New Mexico, weather data for, 868
New York, weather data for, 868
Nielsen, C. E., 634, 636, 637
Night cold storage systems, 599
Niles, P. W. B., 560
Nimbus satellite, 6, 8, 9
NIP (Eppley normal-incidence pyrheliometer), 46
Niyogi, B., 541
NOAA (U.S. National Oceanic and Atmospheric Administration), 55, 59
NOCT (nominal operating cell temperature), 758
Nomenclature:
radiation, 859–860
symbols list, 856–859
Nominal operating cell temperature (NOCT), 758
Nonabsorbing glass, solar transmittance of, 205
Nonimaging concentrators, 326
concentration ratios of, 326
optical characteristics of, 337–344
Normal-incidence pyrheliometer (NIP), 46
Normalized radiation levels, 37
Norris, D. J., 50, 51, 67
North America, weather data for, 866–868
Northeast trade winds, 778
Norton, B., 491
NREL, see National Renewable Energy Laboratory
NSDN (U.S. National Solar Data Network), 685–686
NSRDB (National Solar Radiation Data Base), 55, 863
Nusselt number, 149–150
O
Oberndorfer, G., 384
Odeillo, France solar house, 566, 568
Offenhartz, P. O., 400
Off-peak periods, auxiliary electric energy for, 533–535
O’Gallagher, J. J., 344
Ohanesian, P., 392
Olgyay, V., 546
Olseth, J. A., 91
Olson, T. J., 597–599, 622
Once-through air heating, 607–611
Once-through water heating, 613–614
One-dimensional wind turbine model, 786–790
On-line plots (CombiSys), xxiii
Ontario, weather data for, 866
Oonk, R. L., 581, 584, 654
Opaque materials:
measurement of properties, 186–188
optimum properties, 195–196
radiation characteristics of, see Radiation surface characteristics
Open-circuit air heating, 607–611
Operating costs:
defined, 448
for industrial process heating, 606
Optical characteristics/properties:
of compound parabolic concentrators, 338–344
of concentrating collectors, 334–335
of cover systems, 206–211
of nonimaging concentrators, 337–344
Optical system (concentrating collectors), 322, 323, 334–335
Optimum properties, of opaque materials, 195–196
Oregon, weather data for, 868
Orgill, J. F., 75, 76
Orientation:
concentrating collectors, 324–325
compound parabolic concentrators, 345–349
of linear imaging concentrators, 354–359
and monthly average daily radiation, 112–114
in series arrays with sections having different orientations, 435–437
Ottabasi, U., 277
Overall heat loss coefficient, 240–254
Overhangs:
average shading factors for, 870–885
in passive heating systems, 547–552
shading by, 34–35
Overheating (active building heating systems), 535
Pebble beds, 384. See also Packed beds
Perers, B., 295
Perez, R. R., 86, 91, 93–96
Perforated plates, heat transfer and pressure drop in, 167–168
Performance:
of concentrating collectors, 327–334
compound parabolic concentrators, 332–334, 349–351
linear imaging concentrators, 328–332
receiver thermal losses, 327–328
of flat-plate collectors, 287–298
basic method of testing, 290
efficiency tests, 290–295
general test procedure, 291
incident angle tests, 290, 295–297
in situ, 309–310
test data for, 289, 299–307
time constant, 290, 297–298
modeling, see System thermal calculations of partially shaded collectors, 433–435
predicting, 43
solar cooling performance factor, 590–591
of solar ponds, 637–639
Peterson, L. J., 154
Petitt, R. B., 192, 196
Phase change storage systems:
active building heating systems, 527–529
materials/media for, 396–400
Photoelectric sunshine recorder, 53
Photons, 746
Photon radiation, 139
Photosphere (sun), 4–5
Photovoltaic converters, see Solar (photovoltaic) cells
Photovoltaic pyranometers, 50
Photovoltaic Specialists Conferences, 745
Photovoltaic (PV) systems, 745–771
applications, 764–765
cell temperature, 757–759
controls, 763
converters (solar cells), 746–757
design procedures, 765–770
direct-coupled systems load characteristics, 759–763
generator characteristics and models, 747–757
high-flux generators, 770–771
maximum power point trackers, 763
Pipe loss factors, 423, 426–429
Index

PTTI (principal payment, interest, taxes, and insurance), 452–453
Planck’s law, 140–141
Planetary wind patterns, 778
Plug flow approach (storage tanks), 379, 382–384
Polarization, 204–207
Poole, D. R., 401
Prandtl number, 149–150
Precision spectral pyranometer (PSP), 48, 49
Present worth, 455–456, 459–462
Present-worth factor (PWF), 456–458
Pressure drop:
in flat-plate collectors, 308–309
in packed beds, 165–167
in perforated plates, 167–168
Price, H., 628
Prigmore, D. R., 597
Probert, S. D., 491
Proceedings of the 1957 Solar Furnace Symposium, 322
Proceedings of the 1978 DOE Workshop on Systems Studies for Central Solar Thermal Electric, 629
Proceedings of the ERDA Solar Workshop, 629
Proctor, D., 295, 298, 645, 668
Product storage, 375. See also Energy (product) storage
Profile angle, 17, 19
Programmed orienting systems, 325
Projected area, 713
Property taxes, on installations, 449
PSP (Eppley precision spectral pyranometer), 48, 49
Public Utilities Regulatory Policies Act (PURPA), 625
Puerto Rico, weather data for, 866
PV systems, see Photovoltaic systems
PWF (present-worth factor), 456–458
Pyranometers, 44, 48–53
Pyrheliometers, 44–48
Pyrheliometric scale, 46–48
Radiant exitance, 10
Radiant exposure, 10
Radiant self-exittance, 10
Radiation flux, 144–146
Radiation heat transfer coefficient, 147–149
Radiation intensity, 144–146
Radiation surface characteristics, 173–199
absorptance, 174–176
broadband, 182–183
calculation of, 183–186
of cavity receivers, 197–198
measurement of, 186–188
reflectance and, 181–182
angular dependence of solar absorptance, 196–197
emittance, 174–176
broadband, 182–183
calculation of, 183–186
measurement of, 186–188
reflectance and, 181–182
Kirchhoff’s law, 176–177
measurement of properties, 186–188
optimum properties, 195–196
reflectance, 177–181
absorptance, emittance, and, 181–182
measurement of, 186–188
specular, 198–199
selective surfaces, 188–195
specularly reflecting surfaces, 198–199
Radiation tables, 142–144
Radiosity, 10
Radosevich, L. G., 369, 630, 632
Raithby, G. D., 152, 153
Randall, K. R., 153, 155, 158
Rankine cycle cooling systems, 596–599
Rauschenbach, H. S., 745, 747
Rayleigh number, 149–150
Rayleigh scattering, 60–61
Raymond, E., 506, 527
Ray-trace methods:
for evaluating concentrating collectors, 361
optical properties of cover systems, 206, 209
Read, K. A., 297
Read, W. R., 611, 645
Read, W. R. W., 497
Receivers (concentrating collectors), 322–324, 326
central-receiver collectors, 368–369
CPC-type concentrators and shape of, 343–344

R
Receivers (concentrating collectors)  
(continued)  
intercept factor, 334  
loss coefficients for, 363  
thermal losses from, 327–328  
Recirculating air heating, 611–613  
Recirculating water heating, 615–617  
Reflectance, 85, 177–181  
and absorptance, 181–182  
absorptance, emittance, and, 181–182  
of cover systems, 206–211  
and emittance, 181–182  
measurement of, 186–188  
specular, 198–199  
Reflection:  
and radiation transmission through glazing, 202–206  
through two cover interfaces, 204  
Refractive indices, 203–206  
Refrigiration, 575  
Reindl, D. T., 75, 76, 91, 92, 575  
Remund, J., 664  
Retrofit heaters:  
building heating, 537  
industrial processes, 605, 606  
water, 496–497  
Return on investment (ROI), 467  
defined, 454  
for industrial process heat, 606  
Reversing layer (sun), 5  
Richtmyer, F. K., 140  
Riggs, J. L., 447  
Robinson, N., 5, 10, 44, 62  
Robitzsch pyranometers, 50  
Rock pile, 384. See also Packed beds  
Rohsenow, W. M., 160  
ROI. see Return on investment  
Romero, M., 629, 633  
Roofs:  
collector-storage:  
costs of, 571  
passive building heating systems, 557–561  
double, for passive cooling, 601  
Rooms, absorptance of, 229–230  
Roulet, J. R., 654  
Ruegg, R. T., 447  
Russia, weather data for, 866  
Ruth, D. W., 77, 79, 132  
S  
Safety, with flat-plate collectors, 312  
Safwat, H. H., 295  
Salt-gradient solar ponds, 635–637  
Salt production, 646  
Saluja, G., 257  
Sander, D. M., 417  
Sandia National Laboratories, 764, 765, 770  
Santala, T., 193  
Sapsford, C. M., 493  
Sargent, S. L., 142, 577, 597  
Sarofim, A. F., 146  
Saunier, G. Y., 74  
Scaling problems (water heating), 486  
Scattering (radiation), 59–60  
Schmidt, R. N., 192  
Schmitt, D., 665  
Schöffer, P., 748n.1, 771  
Schroder, D. K., 747  
Schumann, T. E. W., 386  
Schwedler, M. C. A., 561, 562  
SCPF (solar cooling performance factor), 590–591  
SCRS (Solar Constant Reference Scale), 46  
Seasonal energy storage systems:  
active building heating systems, 530–533  
large systems, 394–396  
Seasonal industrial processes, 606–607  
Sebald, A. V., 558  
See, D. S., 646, 647  
SEF (solar energy factor), 498, 499  
SEGS (Solar Electric Generating Systems), 624–628  
Selcuk, K., 280  
Selcuk, M. K., 324, 647  
Selective surfaces, 188–192  
absorptance and emittance, 188–191  
directional selectivity, 193–194  
mechanisms of selectivity, 192–195  
Seraphin, B. O., 193  
Series arrays:  
with sections having different orientations, 435–437  
system thermal calculations for, 431–433  
Series solar energy–heat pump systems, 523, 524  
Shading, 29–37  
of central-receiver collectors, 368  
of collectors in multirow arrays, 35–37  
and flat-plate collector performance, 271–272
by overhangs or wingwalls, 34–35
average shading factors for overhangs, 870–885
in passive heating systems, 547–552
in passive cooling systems, 601
performance of partially shaded collectors, 433–435
by trees, buildings, or other obstructions, 30–34
Shallow-pond water heating, 617–619
Shepard, C. M., 402
Sheridan, N. L., 101
Sheridan, N. R., 576, 577, 653
Shewen, E. C., 166, 167, 280
Short-cut simulations, 669
Short-wave radiation, 43
Shurcliff, W. A., 539, 546
SIAP, 50
Siegel, M. D., 765
Siegel, R., 142, 146, 176, 202, 206, 209
Silver disc pyrheliometer, 45
Simmons, J. A., 400
Simon, F. F., 291
Simpson, W. T., 611, 612
Simulations, 422, 653–666
in active system design, 668–669
air conditioning, 585–588
and experiments, 655, 663
of heat pump–solar energy heating systems, 524–526
information from, 655–656
limitations of, 666
meteorological data for, 663–666
programs for, 653–654
short-cut, 669
of sunspaces, 561–562
TRNSYS program, 656–662, 800–803
utility of, 654–655
Singapore, weather data for, 865
Sjerps-Koomen, E. A., 232
Skartveit, A., 91
Skinrood, A. C., 369, 630, 632
Skoda, L. F., 311
Sky models, 85
anisotropic sky, 91–97
isotropic sky, 89–90
Sky radiation, 147–148. See also Diffuse radiation
anisotropic sky, 91–97
clear-sky radiation estimation, 68–71
isotropic sky, 89–90, 103–106
Sky radiation cooling systems, 600
Slope, 12
Sloped surfaces, available solar radiation on, 84–89
anisotropic sky, 91–97
average radiation:
isotropic sky, 103–106
KT method, 107–112
isotropic sky, 89–90, 103–106
SLR (solar-load ratio) method, 712–721
SMARTS program, 63
Smith, C. C., 609, 610
Smith, R. N., 398
Sokolov, M., 496
Solar Age, 311
Solar altitude angle, 13, 19, 20
Solar aperture, 713, 714
Solar azimuth angle, 13, 16, 19, 20
Solar (photovoltaic) cells, 746–747. See also Photovoltaic (PV) systems
absorptance of, 231–234
maximizing output of, 763
modules of, 749
temperature of operation, 757–759
used with concentrators, 771
voltage-current relationships of, 747
Solar constant, 5–6
Solar Constant Reference Scale (SCRS), 46
Solar cooling performance factor (SCPF), 590–591
Solar-electrical systems, see Thermal power systems
Solar Electric Generating Systems (SEGS), 624–628
Solar Energy (journal), 545
Solar energy factor (SEF), 498, 499
Solar energy–heat pump systems:
active building heating systems, 521–527, 686–690
for seasonal storage, 530
Solar Energy Unit, University College Cardiff, 669
Solar fraction, 444–445, 546
Solar furnaces, 322. See also Concentrating collectors
Solar geometry:
beam radiation:
angles for tracking surfaces, 20–23
direction of, 12–20
ratio on tilted surfaces to horizontal surfaces, 23–29
Solar geometry (continued)
shading, 29–37
of collectors in multirow arrays, 35–37
by overhangs or wingwalls, 34–35
by trees, buildings, or other obstructions, 30–34
solar constant, 5–6
Solar house (term), 505. See also individual houses, e.g.: MIT House IV
Solarimeters, 44
Solar-load ratio (SLR) method, 712–721
Solar-mechanical systems. See also Thermal power systems
cooling, 596–599
thermal conversion systems for, 621–622
Solar noon, 17
Solar One (solar house, University of Delaware), 527, 757
Solar One power plant (California), 369, 630–633
Solar ponds, 635–640
applications of, 639–640
salt-gradient, 635–637
theory of, 637–639
Solar position charts, 20, 30
Solar radiation, 3–41
angles for tracking surfaces, 20–23
available, see Available solar radiation
beam radiation ratio on tilted to horizontal surfaces, 23–29
defined, 43
definitions related to, 9–11
direction of beam radiation, 12–20
extraterrestrial radiation on horizontal surfaces, 37–41
shading, 29–37
solar constant, 5–6
solar time, 11–12
spectral distribution of extraterrestrial radiation, 6–8
the sun, 3–5
variation of extraterrestrial radiation, 8–9
Solar Radiation and Radiation Balance Data, 55, 863
Solar radiation network (SOLRAD), 59
Solar Rating and Certification Corporation (SRCC), 299n.18, 498
Solar-related methods, for cooling, 599–601
Solar savings, 449–450, 461–463
Solar savings fraction, 444–445
in analysis of system economics, 475
passive systems, 713
Solar sky radiation, see Diffuse radiation; Sky radiation
Solar storage tank, in CombiSys, xx
Solar time, 11–12
Solar Two power plant (California), 369, 633
Solar wall, 713
SOLCOST method, 669
SOLMET program, 55n.4, 59
SOLRAD (solar radiation network), 59
Souka, A. F., 295
South Africa, weather data for, 865
South America, weather data for, 869
Southeast trade winds, 778
Sowell, R. P., 192, 196
Sowell, R. R., 192, 196
Space heating. See also Building heating
in CombiSys, xx, 798
degree-day method, 412–415
and water heating, 497
Spain, weather data for, 866
Sparrow, E. M., 161, 163
Spectral dependence, of transmittance through glazing, 215–218
Spectral distribution:
of extraterrestrial radiation, 6–8
of total solar radiation, 61–63
Spectrolab pyranometer, 48
Specular reflectance, 177, 198–199
Spencer, G. H., 361
Spencer, J. W., 9, 11, 14
Speyer, E., 277n.9, 530
Spiegler, K. S., 647
Sputtering processes, 193
SRCC (Solar Rating and Certification Corporation), 299n.18, 498
Stagnation (equilibrium) temperatures (flat-plate collectors), 310
Stanhill, G., 77, 79
Stefanakos, E., 640
Stefan-Boltzmann equation, 141–142
Steinmann, D. E., 613
Stewart, R., 44, 51, 53
Stirewalt, E. N., 745
Storage, see Energy (product) storage
Storage tanks:
for non-energy products of processes, 375
stratification in, 379–384
in hot-water systems, 481
multinode approach, 379–382
plug flow approach, 379, 382–384
water, 376–379
Storage walls, see Collector-storage walls
Stratification (in storage tanks), 379–384
in hot-water systems, 481
multinode approach, 379–382
plug flow approach, 379, 382–384
Streed, E. R., 289, 293
Stuetzle, T., 328, 333
Suhr, H. B., 646
Summers, D. N., 285
The sun, 3–5
Sun, Y. T., 548
Sun Angle Calculator, 20
Sunray Energy, 624
Sunrise hour angle, 17, 19
Sun-seeking orienting systems, 325
Sunset hour angle, 17, 19
Sunspaces:
   costs of, 572
   defined, 545
design parameters for, 716
   in passive building heating systems, 229–230, 561–563
Supercooling (energy recovery), 398
Surfaces, radiation characteristics of, see Radiation surface characteristics
Surface azimuth angle, 13
Surface layers, and radiation transmission through glazing, 218–219
Surface orientation, available solar radiation and, 112–114
Swaminathan, C., 577
Swartman, R. K., 577
Swearingen, J. S., 577
Swimming pools:
   heating loads for, 418–420
   water heating for, 502–503
Swinbank, W. C., 148
Symbols list, 856–859
System models, 441–444
System thermal calculations, 422–445
   collector heat exchanger factor, 424–425
   component models, 422–423
   controls, 429–431
duct and pipe loss factors, 426–429
   modified collector equations, 438–441
   performance of partially shaded collectors, 433–435
   series arrays, 431–433, 435–437
   solar fraction, 444–445
   solar savings fraction, 444–445
   system models, 441–444
Szokolay, S. V., 539, 546
T
Tabor, H., 150, 192, 195, 252, 288, 363, 493, 635, 636, 639
Talbert, S. B., 640, 641, 645
Talwalkar, A. T., 647
Tan, H. M., 161
Tanishita, I., 494
Tax credits/deductions, 448, 450, 537
Taylor, K. J., 647
Teagan, W. P., 597
Telkes, M., 397, 506, 527
Temperature(s):
   and efficiency of solar-mechanical systems, 621–622
   in flat-plate collectors:
      equilibrium (stagnation) temperature, 310
      mean fluid/mean plate temperature, 267–268
ground, 601
   in industrial process heat applications, 604–605
   in salt-gradient solar ponds, 636
   of solar cell operation, 757–759
Temperature distributions (flat-plate collectors), 238–240
collector efficiency factor, 257–261
   in flow direction, 261–262
   between tubes, 254–261
temps, R. C., 92
Terrell, R. E., 622
Tesfamichael, T., 296
Tests:
   for flat-plate collectors, 289–298
      basic method of testing, 290
      efficiency tests, 290–295
general test procedure, 291
      incident angle tests, 290, 295–297
time constant, 290, 297–298
   of water heaters, 497–499
Test data (flat-plate collectors), 289, 299–302
   conversion of, 302–305
   flow rate corrections, 305–307
Texas, weather data for, 868
Theilacker, J. C., 107, 109
Thekaekara, M. P., 6, 9, 44, 60
Thermal capacitance, building, 417
Index

Thermal conversion systems, 621–622
Thermal power systems, 621–633
  central-receiver systems, 628–629
  Gild Bend pumping system, 622–624
  Luz systems, 624–628
  Solar One power plant, 630–633
  Solar Two power plant, 633
  thermal conversion in, 621–622
Thermal radiation, 138
Thermosyphon, 479. See also Passive
  (natural circulation) water heaters
Theunissen, P-H., 297, 336
Thom, H. C. S., 413
Thomas, R. N., 5
Thompson, T., 382
Thomsen, S. M., 218
Thornton, J. A., 193
Threlkeld, J. L., 622
Tilted surfaces, ratio of beam radiation on
  horizontal surfaces to, 23–29
Time, solar vs. standard, 11–12
Time constant:
  defined, 297
  and flat-plate collector thermal performance,
    290, 297–298
Time-dependent loads, 409–411.
  See also Loads
Time value of money, 454–455
TMY, see Typical meteorological year
Total load coefficient, 713
Total solar radiation, 10
Touloukian, Y. S., 188
Townsend, T. U., 747, 762
Tracking surfaces, angles for, 20–23
Trade winds, 778
Transmittance:
  of cover systems, 206–211
  for diffuse radiation, 211–213
  effects of dust and shading on,
    271–272
  through glazing, 202–234
  absorption, 206, 219–229, 231–234
  optical properties of cover systems,
    206–211
  and reflection of radiation, 202–206
  spectral dependence of transmittance,
    215–218
  and surface layers, 218–219
  surface layers’ effects on, 218–219
  transmittance-absorptance product,
    213–215
  transmittance for diffuse radiation,
    211–213
Transmittance-absorptance product, 213–214,
  268–271
Transparent insulation, 415–416
Transparent Insulation Technology, 561
Trewartha, G. T., 66
Trickett-Norris pyranometer, 48
TRNSED:
  defined, 799
  inputs and default parameters for, xx–xxii,
    799–800
TRNSYS, 656–662. See also Simulations
  CombiSys version of, xix. See also
  CombiSys
  components and combinations in library of,
    657–659
  example of, 660–662
  running simulation with, 800–803
  TRNSED front-end of, xx–xxii, 799
  Users Manual, 491, 561
  Trombe, F., 194, 392, 393, 558, 566
  Trombe-Michel walls, 545n.1
  Trombe walls, 545n.1
  Tschermitz, J. L., 611, 612
  Tube collectors, 275
    temperature distributions between tubes,
      254–261
    thermal performance test data for, 301–302
  Tüller, S. E., 77, 79
  Tybout, R. A., 536, 654
  Typical meteorological year (TMY), 59, 664,
    665
U
  Ukraine, weather data for, 866
  Uncertainties, in system economics, 472–475
  Unger, T. A., 192
  U.S. Department of Energy, 654, 776
  U.S. Forest Products Laboratory, 611
  U.S. Home Finance Agency, 150
  U.S. Hydrographic Office, 20
  U.S. National Oceanic and Atmospheric
    Administration (NOAA), 55, 59
  U.S. National Solar Data Network (NSDN),
    685–686
  United States, weather data for, 863, 866–868
  University of Delaware, 527
  University of Houston-Sandia, 368
  University of Minnesota, 199
  University of Queensland, Australia, 577
Unutilizability ("double-U") design method
(passive systems):
collector-storage walls, 727–735
direct gain, 721–727
Utilizability (of available solar radiation):
daily, 126–132
generalized, 118–126
Utilizability methods, 668, 692–709
daily utilizability, 696–709
hourly utilizability, 693–696
Utzinger, D. M., 393, 547, 549–551, 559,
728n.4
Utzinger, M. D., 558
Vacuum sputtering processes, 193
Van Koppen, C. W. J., 379, 490
Vant-Hull, L. L., 47, 368
Variation, of extraterrestrial radiation, 8–9
Vaxman, B., 496
Vee-corrugated enclosures, heat transfer in, 158
Venezuela, weather data for, 869
Ventilation, passive cooling and, 601
Ventre, J., 745, 752, 763
Vernon, R. W., 291
Vielha Hospital, Catalonia, Spain, 568–570
Villefontaine, France apartment buildings, 568–570
Vindum, J. O., 614
W
Wäckelgård, E., 296
Walls:
collector-storage walls, 392–394
costs of, 571–572
defined, 545
design parameters for, 715
loss control with, 546
passive building heating systems, 557–561
unutilizability design method, 727–735
loss coefficients of, 415–416
solar, 713
wingwalls, 34–35, 547–552
Wallasey School (England), 565, 566
Wang, Y., 486
Ward, D. S., 513, 581
Ward, J. C., 668–715
Warehouse heating, passive, 570
Washburn, J., 192, 195
Water heating, 479–503
antifreeze loop/heat exchanger systems, 480, 481, 484
auxiliary energy for, 486–488
boiling protection, 483–486
costs of, 571–572
costs of, 571–572
common system configurations, 479, 480
economics of, 499–501
energy storage in, 375
f-chart method for, 683–684
forced-circulation systems, 479–481, 488–489
freeze protection, 483–484
going in, 410–412
for industrial processes, 604–605
once-through, 613–614
recirculating, 615–617
shallow-pond, 617–619
integral collector storage systems, 494–496
low-flow pumped systems, 490–491
passive (natural circulation) water heaters, 479, 480, 482, 491–494
retrofit heaters, 496–497
scaling problems in, 486
simulation of, xix–xxiv
in space heating and cooling systems, 497
swimming pools, 418–420, 502–503
testing and rating heaters, 497–499
time-dependent loads for, 410–411
Water storage (of energy), 376–379
Watmuff, J. H., 164
Weather data, see Meteorological (weather) data
Wei, J., 419
Weinberger, H., 635
Weinberger, Z., 636
Weir, A. D., 647
Weiss, W., 411, 507, 535, 539
Weibrecht, V., 308
Welford, W. T., 338, 342, 361
Westerman, J. O., 614
White, J. A., 447
Whitlow, E. P., 577
Wiebelt, J. A., 63
Wien’s displacement law, 140–141
Wijeyasingha, N. E., 272, 274
Wilkens, E. S., 635
Williams, D. A., 195, 577
Willson, R. C., 6, 8
Wilson, B. W., 647
Wind convection coefficients, 163–165
Wind duration curve, 781–782
Wind energy, 774–796
   estimating wind turbine average power and energy production, 791–796
   one-dimensional wind turbine model, 786–790
   wind resources, 778–785
Wind Energy Resource Atlas of the United States, 780
Windows:
   in direct-gain systems, 552–555
   direct gain through, 545
   loss coefficients of, 415, 416
   and room absorptance, 229–230
Wind turbines:
   average power and energy production estimation, 791–796
   one-dimensional model, 786–790
   types of, 774–776
Wingwalls:
   in passive heating systems, 547–552
   shading by, 34–35
Winn, C. B., 431, 669
Winston, R., 338, 342, 343, 361
Winter, C. J., 629
Wirsum, M. C., 288, 610, 611
Wisconsin, weather data for, 868
Wittenberg, L. J., 639
WMO, see World Meteorological Organization
Woertz, B. B., 24n.7, 25, 89, 192, 209, 271, 287
Wohlers, H. C., 401
Wolf, M., 745
World Meteorological Organization (WMO), 44, 46, 48, 55
The World Network, 55, 863
World Radiation Center (WRC), 6, 7
World Radiometric Reference (WRR), 46
World Weather Records, 863
WRC (World Radiation Center), 6, 7
WRR (World Radiometric Reference), 46
Wuestling, M. D., 490
Y
Yanagimachi, M., 600, 622
Yang, K. C., 613
Yanishevskiy pyranometer, 48
Yanishevskiy pyrheliometer, 47
Yellott, J. I., 44, 560, 600
Young, A., 10n.3
Yusoff, M. B., 310, 429
Z
Zarmi, Y., 428n.4, 493, 502
Zenith, 16
Zenith angle, 13
Zero-storage-capacity building, hypothetical, 722, 737–738
Zhang, H-F., 278, 279
Zollner, A., 496