

# **An Annotated Bibliography of Greenhouse Energy Conservation and Management**

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# AN ANNOTATED BIBLIOGRAPHY OF GREENHOUSE ENERGY CONSERVATION AND MANAGEMENT<sup>1</sup>

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Energy management for greenhouse operations was traditionally an overlooked concern in technical and research literature until the oil embargo of 1973-74. Since that time, much emphasis has been placed on energy conservation, management and alternatives. However, many of these reports have been published in extension newsletters, trade magazines and other popular forms for the greenhouse grower audience rather than the conventional research publications.

In March 1978, the Ohio Agricultural Research and Development Center received a grant from the Ohio Department of Energy to develop energy conservation measures for commercial greenhouses and to develop educational programs and publications for the greenhouse industry. The first step in this effort was an extensive literature review of all articles, papers and bulletins that could be obtained with the greatest emphasis on the past six years. Much of this information has been summarized in practical terms and recommendations in two subsequent publications: 1) "Conserving Energy in Ohio Greenhouses", OARDC Spec. Circ. 102, Ext. Bul. 651, November 1979 by Phillip C. Badger and Hugh A. Poole, and 2) "Management Practices for Conserving Energy in Ohio Greenhouses", OARDC Spec. Circ. 104, Ext. Bul. 668, July 1980 by Hugh A. Poole and Phillip C. Badger.

This annotated bibliography is intended to provide assistance to others who are interested in greenhouse management and research. A total of 1373 references are cited and key terms have been assigned to them for each reference. The review of literature was terminated May 1, 1980, and does not include citations that were found in literature reviews contained in the papers or articles. With the exception of citations that have an asterisk (\*) following the key terms, the article was reviewed by the authors and assigned one or more of 14 key terms. The articles not reviewed were obtained from a print-out of related articles from the USDA Library in Beltsville, MD. The key words were assigned by the authors without benefit of a review and hence, may not be complete.

Fourteen key terms were selected to identify the relevant information in the references. Such terms as greenhouse, energy and conservation were not used to avoid redundancy. The following key terms were used:

- A. Boiler Operation (maintenance and water treatment)
- B. Cooling and Ventilation
- C. Economics
- D. Environment (light intensity, carbon dioxide levels, humidity, and temperature)

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- E. General Information (fuel availability, greenhouse structures and construction, heat losses, steam generators, politics and windbreaks)
- F. Glazing
- G. Heating (unit heaters, distribution, soil, air and water)
- H. Insulation (roof, sidewalls and foundation)
- I. Maintenance (greenhouse)
- J. Modification (structural and internal)
- K. Production Practice (spacing, cultivars, nutrient film technique, bag culture, cultural practices and closing facilities)
- L. Soil Treatment (steam sterilization and fumigation)
- M. Solar Energy
- N. Waste Heat and Alternative Sources

Each reference is presented in alphabetical order by author, followed by appropriate key terms. Following the 1373 citations, the key terms are cross-referenced to the number preceding the citation numbers for convenience.

It is hoped that this effort will aid others who attempt to meet the challenges of good, efficient management of a precious resource by the greenhouse industry. Hopefully, others may add to this effort and continue to update and improve this first effort.

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G. HEATING (420 Citations)

1, 5, 6, 10, 11, 16, 18-20, 28, 30, 39, 40, 44, 46, 49, 54, 60, 68, 70-72, 79, 81, 82, 86, 88, 90, 97, 102-104, 106, 115, 117, 122, 129, 132-134, 140, 142, 152, 153, 157, 159-161, 163, 166-169, 175, 178-182, 183-186, 188-190, 192, 193, 196-199, 202, 204, 205, 207, 210, 212, 214, 217-220, 222, 224-229, 233, 235, 237, 241, 242, 246, 247, 249, 252, 253, 257, 258, 261, 263, 267, 278, 280, 285-287, 292, 293, 295, 297, 301, 304, 306, 307, 316-318, 326, 328, 330, 332, 335, 336, 338, 340, 345, 360, 367, 373, 374, 377, 396, 398, 400, 411, 413, 416, 419, 421-423, 426, 427, 431, 432, 436-438, 440, 442, 443, 446, 447, 457, 459, 462, 471-473, 477, 481, 482, 484, 492, 495-497, 501, 514, 516, 524, 528, 531, 536, 539, 547, 548, 562, 564, 565, 591, 592, 600, 603, 606, 609, 621, 623, 628, 630, 634, 639-643, 646, 648, 652, 657-659, 664, 675, 679, 682, 686, 689, 693, 697, 703, 710, 726, 735, 739, 740, 748, 754, 768, 777, 788, 789, 796, 797, 807, 808, 814, 819, 821-825, 827-835, 842, 843, 851, 855-857, 860, 864, 865, 867, 869, 878, 883, 885, 886, 890, 891, 893, 896, 898, 900, 902, 904, 908, 909, 917, 920, 921, 927-929, 937, 940, 950, 951, 954, 958, 959, 971, 974, 985, 986, 988-994, 999, 1003, 1008, 1010-1013, 1016, 1023, 1024, 1028-1031, 1033, 1034, 1041, 1045, 1048, 1049, 1056, 1061, 1068, 1072, 1075, 1076, 1081, 1083-1085, 1089, 1093, 1095, 1098, 1100, 1103-1108, 1112, 1113, 1116, 1117, 1122, 1123, 1126-1131, 1136, 1145, 1148, 1150, 1154, 1157, 1166-1168, 1178, 1180, 1182, 1184-1186, 1188, 1190, 1195-

G. HEATING (420 citations, cont.)

1198, 1203, 1206, 1211, 1218-1220, 1223, 1225, 1226, 1232, 1233, 1238, 1241-1244, 1247, 1255, 1261, 1263, 1265-1269, 1271, 1273-1275, 1277, 1278, 1280, 1283, 1285-1287, 1289-1295, 1297, 1302, 1313, 1330, 1332, 1344, 1345, 1352, 1354, 1356, 1359, 1362-1365, 1372, 1373.

H. INSULATION (290 citations)

6, 10, 11, 16, 18, 27, 46, 47, 51, 54, 57, 59, 68, 80, 85, 87, 88, 91-93, 98, 100, 101, 103, 105, 108, 125, 136, 137, 139, 144, 148-150, 144-158, 163, 170-173, 175, 178, 186, 189, 191, 193, 198, 199, 206, 210, 216, 217, 221, 222, 234, 237, 241, 242, 247, 248, 250, 251, 262, 265-270, 273, 274, 283, 285-287, 293, 295, 302, 309, 310, 325, 355, 360, 364-366, 377, 389, 390, 392, 411, 413, 415, 426, 429, 436, 437, 454, 462, 495, 498, 501, 521, 526, 531, 533, 537, 541-543, 547, 548, 551, 553, 557, 564, 592, 600, 605, 614, 618, 519, 621-623, 626, 634, 641, 642, 657, 662, 679, 688, 693, 707, 708, 716, 719, 722-725, 747, 748, 759, 771-773, 778, 782, 791, 802, 803, 825, 829-832, 835, 841, 851, 855, 856, 865, 878, 880, 886, 901, 903, 905, 912, 914, 927-929, 932, 940, 948, 951, 959, 960, 968-973, 975, 978, 981, 987, 988, 990, 991, 994, 1008, 1009, 1012, 1013, 1016-1023, 1025, 1027, 1031, 1034, 1039, 1041, 1043, 1046, 1048-1050, 1066, 1068, 1081, 1087, 1089, 1102, 1104, 1110, 1112, 1115, 1122, 1124, 1126, 1129, 1130, 1147, 1154, 1180, 1186, 1195, 1203, 1215, 1236, 1237, 1247, 1254, 1262, 1267, 1273, 1274, 1279, 1283-1295, 1297-1307, 1323, 1329, 1335, 1338, 1342, 1343, 1348, 1353, 1356, 1359.

I. MAINTENANCE (75 citations)

10, 11, 108, 148, 163, 189, 190, 199, 214, 217, 222, 241, 242, 247, 266, 275, 287, 293, 302, 360, 366, 411, 413, 436, 444, 445, 462, 498, 521, 548, 564, 592, 623, 642, 716, 769, 851, 856, 865, 886, 915, 927-929, 940, 971, 981, 990, 1009, 1012, 1013, 1016, 1019, 1043, 1046, 1049, 1089, 1116, 1122, 1180, 1186, 1215, 1236, 1247, 1267, 1269, 1285, 1289, 1291, 1292, 1295, 1323, 1327, 1342, 1353.

J. MODIFICATIONS (178 Citations)

6, 8, 10, 11, 16, 18, 27, 46, 47, 51, 54, 57, 59, 68, 80, 85, 87, 88, 91, 93, 98, 100, 101, 103, 105, 108, 125, 136, 137, 139, 144, 148-150, 155-158, 163, 170-173, 175, 178, 186, 189, 191, 193, 198, 199, 206, 210, 216, 217, 221, 222, 234, 237, 241, 242, 247, 250, 251, 262, 265-270, 273, 274, 283, 285, 286, 293, 295, 309, 310, 325, 355, 360, 364-366, 377, 389, 390, 392, 411, 413, 415, 426, 429, 436, 437, 454, 462, 495, 498, 501, 521, 531, 533, 547, 548, 551, 553, 557, 564, 592, 600, 605, 609, 614, 618, 619, 621-623, 626, 634, 641, 642, 657, 679, 688, 693, 707, 708, 716, 719, 723-725, 747, 748, 769, 771-773, 778, 782, 791, 802, 825, 829-832, 835, 841, 856, 865, 878, 880, 886, 901, 903, 905, 912, 914, 927-929, 932, 940, 948, 951, 959, 960, 968-973, 975, 978, 981, 987, 988, 990, 991, 994, 1008, 1009, 1012, 1013, 1016-1023, 1025-1027, 1031-1034, 1039-1041, 1043, 1046, 1048-1050, 1066, 1068, 1081, 1087, 1089, 1102, 1104, 1110, 1112, 1115, 1122, 1124, 1129, 1147, 1150, 1154, 1180, 1186, 1195, 1203, 1215, 1236, 1237, 1247, 1254, 1262, 1267, 1273, 1274, 1279, 1283-1295, 1297-1307, 1323, 1329, 1335, 1338, 1341-1343, 1348, 1353, 1356, 1359.

K. PRODUCTION PRACTICE (216 Citations)

22, 35, 42, 44, 45, 53, 55, 76, 85, 88, 96, 109, 111, 112, 116, 119, 121, 123, 127, 129, 132, 134, 135, 138, 141, 143, 147, 150, 151, 154, 171, 189, 205, 206, 208-210, 213, 234, 237, 239-244, 255, 263, 277, 280, 282, 285, 291, 293, 295, 314, 316, 328, 346, 363, 364, 369, 377, 378, 396, 398, 404-409, 414, 420, 424, 425, 434, 435, 439, 446, 449, 462, 464, 467, 472, 476, 478, 506, 508, 509, 511, 517, 522, 525, 531, 543, 547, 548, 556, 608, 620, 634, 639, 642, 649-651, 677, 682, 683, 689, 692, 701, 712, 716, 720, 726, 733, 740, 749-751, 753, 755-760, 765-767, 770, 776, 783, 784, 786, 796, 799-801, 805, 812, 823, 846, 860, 862, 863, 865, 871, 886, 897, 906, 907, 910, 924, 925, 930, 931, 933, 935, 937, 940, 945, 948, 952, 953, 957, 961, 963, 964, 967, 976, 986, 998, 1002, 1005, 1006, 1013, 1035-1038, 1041, 1046, 1049, 1051, 1052, 1057, 1060, 1062, 1063, 1074, 1089, 1091, 1136, 1138, 1139, 1143, 1176, 1184, 1191, 1194, 1215, 1254, 1271, 1273, 1274, 1280, 1286, 1287, 1317, 1318, 1326, 1356.

L. SOIL TREATMENT (58 Citations)

9, 12, 17, 39, 44, 60, 82, 111, 121, 127, 189, 199, 231, 232, 293, 298, 299, 362, 408, 428, 441, 450, 466, 483, 548, 573, 622, 634, 693, 709, 718, 737, 738, 806, 850, 858, 886, 919, 929, 930, 933, 934, 938, 939, 965, 1007, 1069, 1072, 1077, 1078, 1081, 1085, 1091, 1180, 1184, 1203, 1214, 1323.

M. SOLAR ENERGY (212 Citations)

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N. WASTE HEAT AND ALTERNATIVE SOURCES (118 Citations)

28, 37, 40, 46, 58, 67, 82, 122, 128, 157, 186, 196, 211, 212, 241, 242, 258, 261, 271, 272, 293, 295-297, 301, 313, 317, 318, 327, 338, 339, 344, 345, 442, 443, 462, 470, 473, 479, 493, 494, 510, 561, 585, 591, 595, 596, 603, 626, 642, 645, 646, 654, 690, 721, 771, 795, 797, 816, 825, 864, 866, 880, 893-896, 908, 916, 921, 944, 949, 956, 966, 999, 1003, 1028-1030, 1064, 1076, 1081, 1123, 1134, 1144, 1153, 1156, 1159, 1170, 1171, 1181, 1190, 1204, 1219, 1220, 1236, 1238, 1241-1244, 1253, 1286, 1289-1293, 1295, 1303, 1313, 1315, 1316, 1328, 1342, 1352, 1358, 1360.

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Eastern Ohio Resource Development Center, Caldwell, Noble County: 2053 acres

Jackson Branch, Jackson, Jackson County: 502 acres

Mahoning County Farm, Canfield: 275 acres

Muck Crops Branch, Willard, Huron County: 15 acres

North Appalachian Experimental Watershed, Coshocton, Coshocton County: 1047 acres (Cooperative with Science and Education Administration/Agricultural Research, U. S. Dept. of Agriculture)

Northwestern Branch, Hoytville, Wood County: 247 acres

Pomerene Forest Laboratory, Coshocton County: 227 acres

Southern Branch, Ripley, Brown County: 275 acres

Vegetable Crops Branch, Fremont, Sandusky County: 105 acres

Western Branch, South Charleston, Clark County: 428 acres