USDA FOREST SERVICE
RESEARCH PAPER **NC-170**

Potential for energy recovery from humid air streams

Howard N. Rosen

North Central Forest Experiment Station
Forest Service, U.S. Department of Agriculture

North Central Forest Experiment Station
Robert A. Hann, Director
Forest Service—U.S. Department of Agriculture
1992 Folwell Avenue
St. Paul, Minnesota 55108
Manuscript approved for publication January 30, 1979

1979

POTENTIAL FOR ENERGY RECOVERY FROM HUMID AIR STREAMS

Howard N. Rosen, *Research Chemical Engineer, Carbondale, Illinois*

A prime consideration of the forest products industry is to reduce energy consumption. Since the drying of wood accounts for over half the energy consumed in primary manufacturing of forest products, energy saved here could be substantial. Especially promising for recovery is the energy in the humid air exhausted from dryer vents (Rosen 1978, Corder and Turner 1978). Currently, industry usually exhausts humid air from veneer and lumber dryers directly to the atmosphere without any attempt at recovery.

The practice of recovering heat from exhaust gas streams is not new to the forest products industry. Stack gases from boilers have been passed through "economizers" to preheat the air to the boilers (Woodruff and Lammers 1967). The difference between boiler stack gases and dryer vent streams is that the dryer vent streams contain considerable water vapor; thus, the heat of condensation of the water vapor as well as the heat evolved from a temperature change can be transferred to another stream.

The potential energy available for recovery needs to be determined before the modifications to existing equipment can be justified. The purpose of this paper is to calculate the energy recoverable from vent air streams over a range of dry bulb temperatures, T_{db}, from 200 to 400°F and wet bulb temperatures, T_{wb}, from 100 to 212°F (for notation, see Appendix). The vent air is assumed to pass through a recovery (regenerative) heat exchanger where heat is transferred to another liquid or gas stream for use elsewhere in the processing plant. Vent air temperature drops across the recovery heater, ΔT_r range from 100 to 300°F.

BASIS FOR CALCULATIONS

Assume that the vent air from the dryer goes into the regenerative heat exchanger at a dry bulb temperature T_1 and a humidity W_1 and leaves at T_2 and W_2 (fig. 1). Total pressure remains constant at 1 atmosphere. An enthalpy (heat content) balance on the humid vent air yields:

enthalpy change of vent air stream, Δh_r = sensible heat release of air + sensible and latent heat release of steam

Sensible heat is that evolved as a result of temperature change. Latent heat is that evolved as the result of vapor condensation.

The following discontinuous function, based on one pound of dry air, was used to calculate Δh_r:

Only sensible heat removed ($W_1 \leq W_s$)

$$\Delta h_r = \frac{h_{air} + W_1 \Delta h_{st}}{W_1} \quad (1)$$

Sensible and latent heat removed ($W_1 > W_s$)

$$\Delta h_r = \frac{\Delta h_{air} + W_s \Delta h_{st} + (W_1 - W_s) \Delta h_{cond}}{W_1} \quad (2)$$

where, Δh_{air}, Δh_{st}, Δh_{cond} are the changes in enthalpy of air, steam, and condensate, respectively, based on Btu/lb of air or water.

W_1 is the inlet humidity of the vent air stream in lb water/lb dry air (in Equation 1, $W_1 = W_2$).

W_s is the saturation humidity at T_2 in lb water/lb dry air (in Equation 2, $W_s = W_2$).

The decrease in enthalpy of the vent stream must equal the increase in enthalpy of the heated stream, thus Δh_r is also the recoverable energy from the heat exchanger. The units of Δh_r, Btu/lb water vapor, were thought to be those most useful for calculating total potential energy savings from a dryer vent stream (see examples in the Appendix).

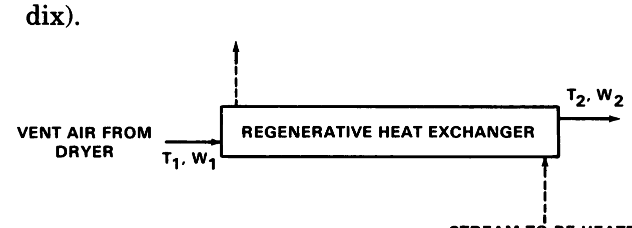

Figure 1.—*Flow streams through regenerative heat exchanger.*

DEVELOPMENT OF RECOVERABLE ENERGY TABLES

Calculations of Δh_r were made for Equations 1 and 2 over a range of T_1 (or T_{db}) from 200 to 400°F, of T_{wb} from 100 to 212°F, and ΔT_r from 100 to 300°F (tables 1-11, p. 5-9). Humidity is usually determined indirectly from readings of wet and dry bulb temperatures. Conversion from values of T_{db} and T_{wb} to humidity can be made from figures 2 and 3.

Further explanation of the terms in Equations 1 and 2, as well as the references from which specific values of these terms were taken, are given below:

Δh_{air} is the enthalpy of dry air at T_1 less the enthalpy change of dry air at T_2 (Zimmerman and Lavine 1964).

Δh_{st} is the enthalpy of water vapor at T_1 less the enthalpy of water vapor at T_2 (Zimmerman and Lavine 1964).

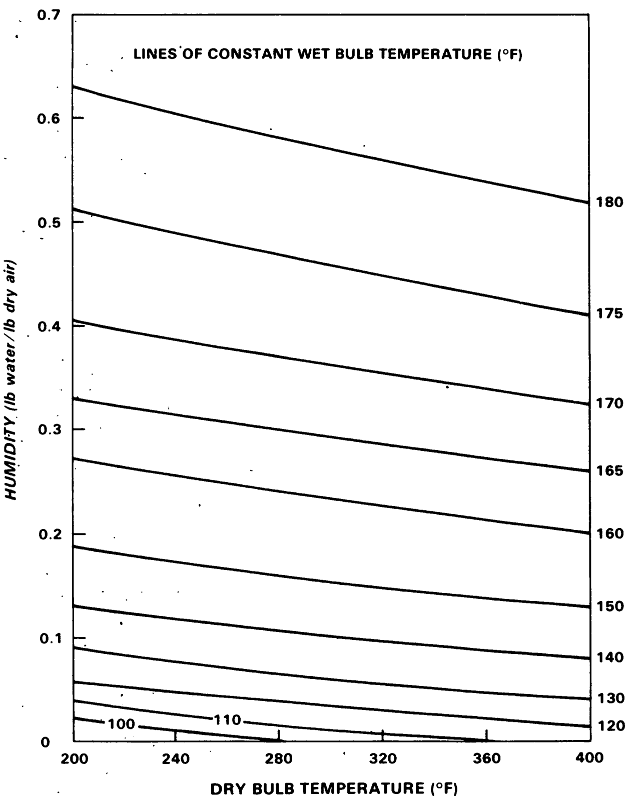

Figure 2.—*High temperature psychrometric chart, wet bulb temperature lines at low humidity range (100 to 180 °F T_{wb}) (Anonymous 1976).*

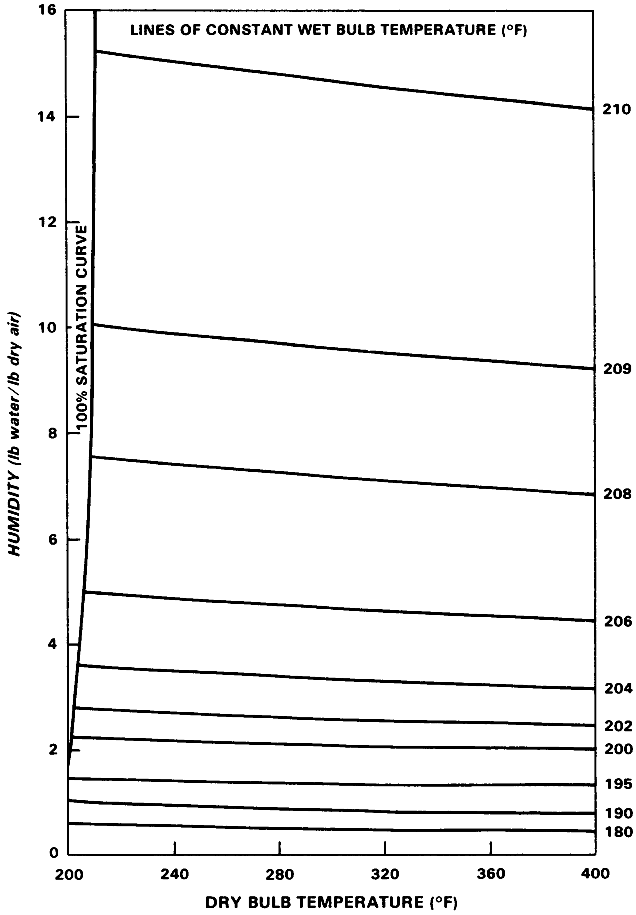

Figure 3.—*High temperature psychrometric chart, wet bulb temperature lines at high humidity range (180 to 210 °F T_{wb}) (Anonymous 1976, Krischer 1956).*

Δh_{cond} is the enthalpy of water vapor at T_1 less the enthalpy of liquid water at T_2 (Zimmerman and Lavine 1964).

W_s (Zimmerman and Lavine 1964).

W_1 (figs. 2 and 3).

Two limitations were placed on the calculations for the recoverable energy tables: first, calculations were not made for $W_1 < 0.001$, since values so small are not of practical value, and second, no calculations were made for $T_2 < 70$°F, since most streams in a wood processing plant are higher than this temperature.

The dotted line in the tables represents the transition from where only sensible heat is recovered to where sensible and latent heat are recovered. All values above the dotted line include only sensible heat recovery. The values at the bottom of each table specifically give Δh_r and T_{wb} at the transition (T^*_{wb}, in parentheses). At this point, T_2 equals the dew point of the vent air stream.

Before examining the implications of the recoverable energy tables, two important concepts are discussed: (1) the difference between the wet bulb temperature and dew point temperature of a humid air stream, and (2) the importance of heat of condensation in energy recovery.

The *wet bulb temperature* is the equilibrium temperature obtained by a small reservoir of water in contact with a large amount of air flowing past it, such that the latent heat carried away by the evaporation of water into the gas is equal to the sensible heat transferred from the gas to the liquid (Bennett and Meyers 1962). The *dew point temperature* (T_{dp}) is the temperature at which a given sample of moist air becomes saturated as it is cooled at constant pressure and humidity. For a given T_{db}, T_{wb}'s are higher than T_{dp}'s but approach each other as T_{wb} increases (fig. 4).

The latent heat of condensation of water is the major portion of the total energy transferred in a regenerative heat exchanger. Almost 81 percent of the enthalpy change of water going from a vapor at 400°F to a liquid at 70°F is latent heat. When air is present with water vapor (i.e. T_{wb}<212°F), the contribution of latent heat to total energy recovery is not as great as in pure steam, but still can be substantial depending on conditions. As shown in figure 5, water will not condense from a humid air stream until the temperature drops below T_{dp} (For the curve at T_{wb} of 160°F, the temperature must go below 155°F). For a given T_{db} and ΔT_r, the percentage of water vapor condensed from the air stream increases as T_{wb} increases. When humid air at 250°F is lowered to 150°F, 99 percent of the water vapor is removed if T_{wb} is 210°F; whereas only 23 percent is removed if T_{wb} is 160°F (fig. 5).

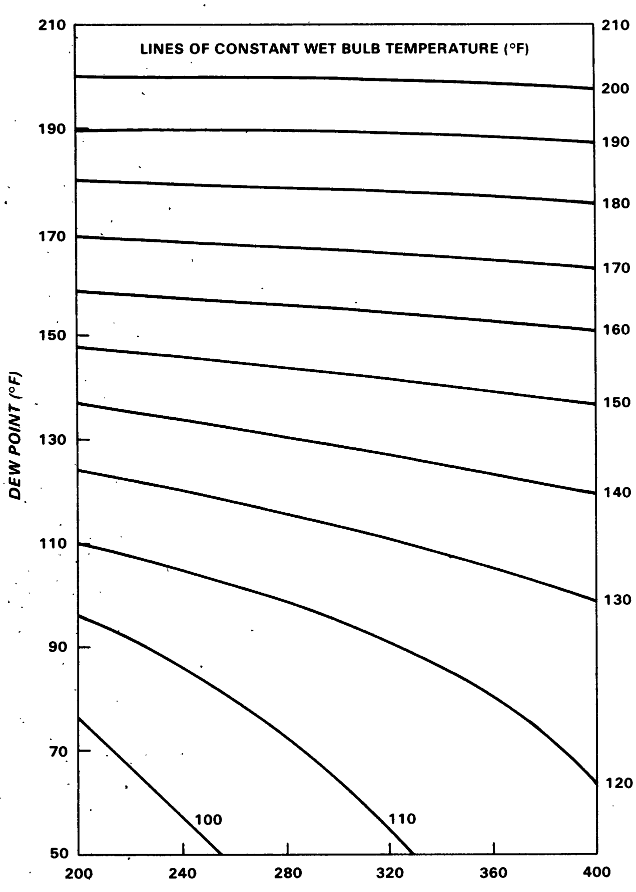

Figure 4.—*Dew point temperatures as related to wet and dry bulb temperatures (Zimmerman and Lavine 1964).*

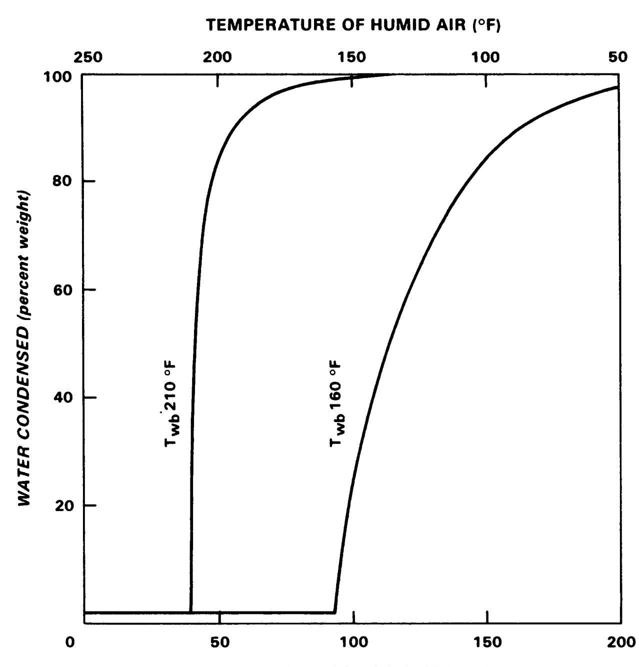

Figure 5.—*Percentages of the total water vapor in air condensed as the temperature of the air initially at 250°F is lowered.*

Typical curves from the data of the energy recovery tables show the complex relation between recoverable energy and T_{wb} for values of T_{db} and ΔT_r (figs. 6 and 7). When only sensible heat is recovered (T_{db} = 400°F, fig. 6), recoverable energy increases as T_{wb} decreases. This increase reflects the sensible heat removed with increasing amounts of dry air required per pound of water to lower the wet bulb temperature. When latent and sensible heat are removed, two types of curves result at constant T_{db}.

In most cases, a minimum recoverable energy exists at T^*_{wb} corresponding to $T_2 = T_1 - \Delta T_r = T_{dp}$. Because Δh_r at T^*_{wb} is a critical point on many of the curves, these values are given at the bottom of the energy recovery tables. Below T^*_{wb} only sensible heat is recovered; above T^*_{wb} both sensible and latent heat are recovered. The other type of curve results when the heat recovery continues to decrease over the range of T_{wb}'s even though latent heat is recovered from the air (fig. 7, ΔT_r= 180 and 200°F). In this case, as T_{wb} decreases, the

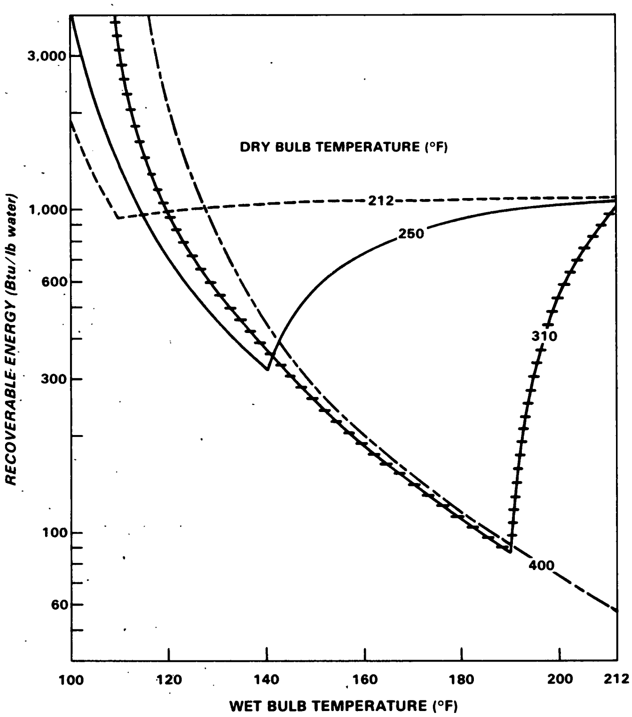

Figure 6.—*Recoverable energy versus wet bulb temperature for several dry bulb temperatures* (ΔT_r = 120°F).

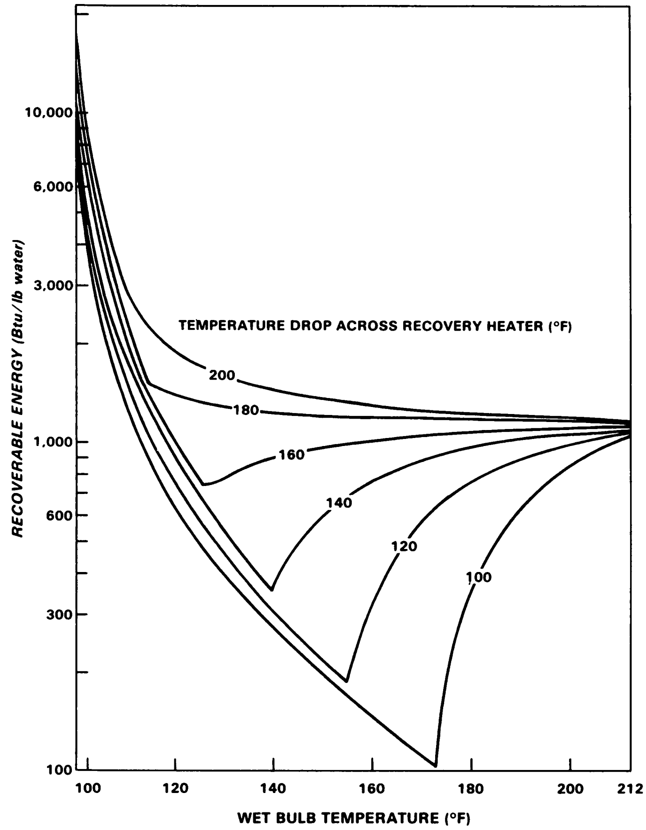

Figure 7.—*Recoverable energy versus wet bulb temperature for several temperature drops across a regenerative heat exchanger* (T_{db} = 270°F).

increasing contribution of the sensible heat of the air more than offsets the decreasing latent heat of the condensing water.

SUMMARY

An excellent potential exists for recovering energy from vent streams of high temperature wood and veneer dryers. The recovery is usually improved if the temperature of the humid air stream is lowered below the dew point so that the latent heat of the water is removed. Vent streams with high humidities are best for energy recovery, since these streams have the largest potential for energy recovery per volume of vent stream.

Table 1.—*Recoverable energy*[1], Δh_r, *in Btu/lb water from a heat exchanger with* $\Delta T_r = 100°F$

Wet bulb temperature, T_{wb}, °F	Vent air dry bulb temperature, T_1, °F 200	212	230	250	270	290	310	330	350	375	400
100	1246	1546	2050	3437	8390	—	—	—	—	—	—
110	711	795	918	1091	1318	1660	2478	4031	11093	—	—
120	725	480	514	567	635	718	807	916	1104	1397	1924
130	850	593	343	364	390	424	460	498	543	612	689
140	920	744	317	253	265	279	293	306	320	343	368
150	968	844	543	187	195	202	209	215	221	228	235
160	1002	908	708	263	146	150	154	157	161	165	169
170	1027	968	838	564	107	109	112	115	117	119	121
180	1045	1005	915	735	351	88	91	91	92	93	94
190	1058	1031	974	851	634	71	73	73	73	73	74
200	1071	1052	1022	965	854	536	59	59	59	59	59
205		1060	1039	1004	939	760	54	54	54	54	54
210		1068	1055	1038	1013	958	50	49	49	49	49
212		1070	1061	1051	1041	1030	1019	48	47	47	47
[2]T^*_{wb}		602	423	259	157	101	68	44			
	(114)	(122)	(137)	(154)	(173)	(191)	(210)				

[1]Only sensible heat recovery above dotted line; sensible and latent heat recovery below.
[2]Recoverable energy when dew point of humid air stream is equal to T_2. The wet bulb temperature corresponding to that dew point, T^*_{wb}, is in parentheses.

Table 2.—*Recoverable energy*[1], Δh_r, *in Btu/lb water from a heat exchanger with* $\Delta T_r = 120°F$

Wet bulb temperature, T_{wb}, °F	Vent air dry bulb temperature, T_1, °F 200	212	230	250	270	290	310	330	350	375	400
100	1495	1855	2459	4122	10106	—	—	—	—	—	—
110	1118	938	1101	1308	1579	1988	2966	4828	13284	—	—
120	1110	1000	617	680	760	860	965	1097	1322	1679	2303
130	1106	1023	663	437	467	507	549	596	651	736	825
140	1103	1040	808	339	316	333	350	367	384	413	441
150	1102	1056	890	569	233	241	250	258	265	273	282
160	1101	1068	952	721	292	180	184	188	192	197	203
170	1100	1075	998	854	587	131	134	137	140	143	145
180	1099	1080	1028	930	747	357	107	109	111	112	113
190		1084	1049	987	876	643	85	87	88	88	89
200		1088	1066	1033	976	863	543	71	71	71	71
205		1089	1073	1050	1015	948	769	65	65	65	65
210		1090	1079	1065	1048	1023	967	59	59	59	59
212		1090	1081	1070	1060	1050	1040	1029	57	57	57
[2]T^*_{wb}		1321	917	532	312	190	121	82	59		
	(103)	(109)	(123)	(138)	(155)	(172)	(191)	(210)			

[1]Only sensible heat recovery above dotted line; sensible and latent heat recovery below.
[2]Recoverable energy when dew point of humid air stream is equal to T_2. The wet bulb temperature corresponding to that dew point, T^*_{wb}, is in parentheses.

Table 3.—*Recoverable energy*[1], Δh_r, *in Btu/lb water from a heat exchanger with* ΔT_r*=140°F*

Wet bulb temperature, T_{wb},°F	Vent air dry bulb temperature, T_1,°F 212	230	250	270	290	310	330	350	375	400
100	2164	2875	4821	11716	—	—	—	—	—	—
110	1604	1288	1530	1840	2322	3454	5622	15521	—	—
120	1400	1137	795	885	1004	1123	1276	1545	1955	2689
130	1291	1113	720	544	592	638	693	760	857	963
140	1240	1117	843	368	388	406	426	449	481	515
150	1194	1110	922	588	281	290	299	309	318	328
160	1176	1108	975	750	287	211	217	223	230	237
170	1150	1103	1018	877	597	155	158	161	165	169
180	1137	1103	1045	946	760	363	126	128	130	132
190	1125	1102	1063	1001	888	655	100	102	103	104
200	1117	1102	1078	1044	987	874	550	83	83	83
205	1114	1101	1084	1061	1025	958	777	75	75	75
210	1111	1101	1089	1075	1058	1033	976	69	69	69
212	1110	1101	1091	1081	1071	1060	1049	1038	66	66
[2]T^*_{wb}	2040 (101)	1141 (111)	623 (124)	366 (139)	222 (155)	142 (173)	95 (192)	69 (210)		

[1]Only sensible heat recovery above dotted line; sensible and latent heat recovery below.

[2]Recoverable energy when dew point of humid air stream is equal to T_2. The wet bulb temperature corresponding to that dew point, T^*_{wb}, is in parentheses.

Table 4.—*Recoverable energy*[1], Δh_r, *in Btu/lb water from a heat exchanger with* ΔT_r*=160°F*

Wet bulb temperature, T_{wb},°F	Vent air dry bulb temperature, T_1,°F 230	250	270	290	310	330	350	375	400
100	3284	5505	13380	—	—	—	—	—	—
110	1893	1747	2101	2643	3942	6417	17711	—	—
120	1549	1239	1011	1142	1281	1455	1761	2232	3068
130	1388	1187	771	673	728	790	866	979	1099
140	1308	1165	891	441	463	485	510	549	588
150	1249	1150	957	606	330	340	352	364	375
160	1212	1138	1004	765	322	249	256	263	270
170	1175	1126	1041	895	605	181	185	189	194
180	1157	1122	1061	960	774	368	146	149	151
190	1142	1117	1077	1014	901	665	115	117	118
200	1131	1114	1090	1056	998	884	557	95	95
205	1128	1113	1095	1072	1035	968	785	86	86
210	1122	1111	1099	1085	1068	1042	986	79	78
212	1121	1111	1101	1091	1080	1069	1058	76	76
[2]T^*_{wb}	2511 (102)	1306 (113)	713 (126)	417 (141)	254 (156)	162 (174)	109 (192)		

[1]Only sensible heat recovery above dotted line; sensible and latent heat recovery below.

[2]Recoverable energy when dew point of humid air stream is equal to T_2. The wet bulb temperature corresponding to that dew point, T^*_{wb}, is in parentheses.

Table 5.—*Recoverable energy*[1], Δh_r, *in Btu/lb water from a heat exchanger with* ΔT_r*=180°F*

Wet bulb temperature, T_{wb},°F	Vent air dry bulb temperature, T_1,°F							
	250	270	290	310	330	350	375	400
100	6190	15078	—	—	—	—	—	—
110	2304	2368	2979	4430	7212	19901	—	—
120	1696	1390	1287	1439	1635	1978	2512	3455
130	1480	1271	813	817	887	972	1101	1238
140	1365	1218	933	519	544	572	617	662
150	1293	1186	987	640	381	394	408	422
160	1241	1167	1026	800	277	285	295	305
170	1197	1149	1063	911	617	207	213	218
180	1175	1139	1078	977	786	176	167	170
190	1157	1132	1091	1029	889	669	130	134
200	1143	1126	1101	1067	1009	894	367	107
205	1138	1124	1106	1082	1046	978	687	97
210	1133	1121	1109	1095	1078	1052	964	89
212	1131	1121	1111	1100	1089	1078	1065	86
[2]T^*_{wb}	2824 (105)	1472 (115)	804 (128)	472 (141)	286 (157)	183 (174)	113 (197)	

[1]Only sensible heat recovery above dotted line; sensible and latent heat recovery below.
[2]Recoverable energy when dew point of humid air stream is equal to T_2. The wet bulb temperature corresponding to that dew point, T^*_{wb}, is in parentheses.

Table 6.—*Recoverable energy*[1], Δh_r, *in Btu/lb water from a heat exchanger with* ΔT_r*=200°F*

Wet bulb temperature, T_{wb},°F	Vent air dry bulb temperature, T_1,°F						
	270	290	310	330	350	375	400
100	16742	—	—	—	—	—	—
110	2842	3308	4929	8007	22091	—	—
120	1927	1556	1601	1814	2195	2787	3832
130	1586	1375	915	984	1078	1220	1373
140	1427	1250	990	603	634	684	733
150	1335	1219	1033	662	436	452	468
160	1271	1196	1061	814	345	323	337
170	1221	1171	1084	928	629	235	241
180	1193	1157	1096	993	793	206	187
190	1170	1145	1106	1042	924	571	147
200	1155	1137	1114	1079	1020	862	118
205	1149	1134	1117	1093	1055	963	492
210	1143	1131	1119	1105	1087	1053	917
212	1140	1130	1120	1109	1098	1085	1072
[2]T^*_{wb}	3144 (107)	1636 (117)	895 (129)	525 (142)	319 (158)	204 (179)	115 (201)

[1]Only sensible heat recovery above dotted line; sensible and latent heat recovery below.
[2]Recoverable energy when dew point of humid air stream is equal to T_2. The wet bulb temperature corresponding to that dew point, T^*_{wb}, is in parentheses.

Table 7.—*Recoverable energy*[1], Δh_r, *in Btu/lb water from a heat exchanger with* ΔT_r=220°F

Wet bulb temperature, T_{wb},°F	Vent air dry bulb temperature, T_1,°F 290	310	330	350	375	400
110	3636	5417	8819	24281	—	—
120	2389	1781	1998	2412	3062	4210
130	1844	1492	1074	1185	1340	1507
140	1577	1364	1032	697	750	805
150	1432	1280	1069	705	495	513
160	1343	1235	1086	845	354	369
170	1268	1197	1103	949	550	264
180	1226	1177	1114	1011	774	205
190	1195	1161	1121	1055	891	433
200	1170	1145	1125	1086	1009	791
205	1158	1143	1127	1103	1053	926
210	1153	1141	1128	1114	1091	1040
212	1150	1140	1129	1118	1105	1092
[2]T^*_{wb}	3457 (110)	1802 (117)	985 (130)	577 (143)	313 (162)	183 (183)

[1]Only sensible heat recovery above dotted line; sensible and latent heat recovery below.

[2]Recoverable energy when dew point of humid air stream is equal to T_2. The wet bulb temperature corresponding to that dew point, T^*_{wb}, is in parentheses.

Table 8.—*Recoverable energy*[1], Δh_r, *in Btu/lb water from a heat exchanger with* ΔT_r=240°F

Wet bulb temperature, T_{wb},°F	Vent air dry bulb temperature, T_1,°F 310	330	350	375	400
110	5906	9615	26516	—	—
120	2452	2178	2633	3336	4587
130	1860	1621	1293	1460	1642
140	1577	1420	1096	817	876
150	1435	1325	1112	578	558
160	1339	1265	1121	771	401
170	1271	1220	1128	909	379
180	1232	1194	1131	989	648
190	1201	1175	1134	1049	846
200	1179	1161	1137	1094	993
205	1168	1156	1137	1111	1048
210	1162	1151	1138	1125	1088
212	1160	1149	1138	1125	1112
[2]T^*_{wb}	3777 (112)	1965 (121)	1076 (132)	554 (148)	305 (167)

[1]Only sensible heat recovery above dotted line; sensible and latent heat recovery below.

[2]Recoverable energy when dew point of humid air stream is equal to T_2. The wet bulb temperature corresponding to that dew point, T^*_{wb}, is in parentheses.

Table 9.—*Recoverable energy*[1], Δh_r, *in Btu/lb water from a heat exchanger with* ΔT_r=260°F

Wet bulb temperature, T_{wb},°F	Vent air dry bulb temperature, T_1, °F 330	350	375	400
110	10410	28707	—	—
120	2786	2851	3612	4964
130	2000	1776	1580	1776
140	1660	1494	1049	947
150	1490	1371	1081	603
160	1377	1295	1105	670
170	1297	1246	1118	852
180	1252	1215	1130	956
190	1216	1189	1135	1031
200	1191	1173	1141	1086
205	1181	1166	1144	1108
210	1172	1161	1145	1125
212	1169	1158	1145	1132
[2]T^*_{wb}	4090 (114)	2132 (123)	1022 (136)	530 (152)

[1]Only sensible heat recovery above dotted line; sensible and latent heat recovery below.

[2]Recoverable energy when dew point of humid air stream is equal to T_2. The wet bulb temperature corresponding to that dew point, T^*_{wb}, is in parentheses.

Table 10.—*Recoverable energy*[1], Δh_r, *in Btu/lb water from a heat exchanger with* ΔT_r=280°F

Wet bulb temperature, T_{wb},°F	Vent air dry bulb temperature, T_1,°F 350	375	400
110	30897	—	—
120	3391	3892	5350
130	2204	1855	1913
140	1753	1527	1020
150	1543	1385	1031
160	1409	1306	1075
170	1326	1252	1106
180	1274	1221	1123
190	1232	1197	1134
200	1202	1180	1144
205	1192	1173	1148
210	1182	1167	1151
212	1178	1165	1152
[2]T^*_{wb}	4409 (116)	1973 (126)	962 (140)

[1]Only sensible heat recovery above dotted line; sensible and latent heat recovery below.

[2]Recoverable energy when dew point of humid air stream is equal to T_2. The wet bulb temperature corresponding to that dew point, T^*_{wb}, is in parentheses.

Table 11.—*Recoverable energy*[1], Δh_r, *in Btu/lb water from a heat exchanger with* ΔT_r*=300°F*

Wet bulb temperature,	Vent air dry bulb temperature, T_1,°F	
T_{wb},°F	375	400
120	4168	5727
130	2419	2048
140	1829	1539
150	1578	1385
160	1438	1310
170	1338	1258
180	1261	1227
190	1232	1202
200	1211	1185
205	1199	1179
210	1189	1174
212	1185	1172
[2]T^*_{wb}	3996 (120)	1822 (131)

[1]Only sensible heat recovery above dotted line; sensible and latent heat recovery below.

[2]Recoverable energy when dew point of humid air stream is equal to T_2. The wet bulb temperature corresponding to that dew point, T^*_{wb}, is in parentheses.

LITERATURE CITED

Anonymous. 1976. Psychrometric chart, Bulletin 491-1/76, Proctor and Schwartz, SCM Corp., Philadelphia, Pennsylvania.

Bennett, C. O., and J. E. Meyers. 1962. Momentum, heat, and mass transfer. p. 552. McGraw-Hill Book Company, Inc., New York.

Corder, S. E., and C. Turner. 1978. Potential for energy recovery from lumber dry kilns. Paper presented at the 32nd Annual Forest Prod. Res. Soc. Meeting in Atlanta, Georgia.

Krischer, O., and K. Kroll. 1956. Drying technology. The scientific principles of drying technology, Vol. I. Springer, Berlin. p. 32.

Rosen, Howard N. 1978. High temperature predrying of wood. *In* Proc. of the Western Dry Kiln Club. 29th Annual Meet. May 11-12, 1978. Redding, California. p. 1-10.

Woodruff, E. B., and H. B. Lammers. 1967. Steam plant operation. McGraw-Hill, Inc., New York. p. 25.

Zimmerman, O. T., and Irvin Lavine. 1964. Industrial research service's psychrometric tables and charts. Industrial Research Service, Inc., Dover, New Hampshire. p. 24-28, 126-130, 138-141.

APPENDIX

I. Example problems demonstrate how to use the energy recovery tables.

Example A—A veneer dryer handles 5 tons per hour of green veneer at 80 percent moisture content and dries the veneer to 5 percent moisture content. The dry and wet bulb temperatures of the vent stacks are 290 and 190°F, respectively. Assuming that 90 percent of the water vapor removed from the veneer goes through the vent stacks (10 percent loss in leaks), how much energy can be recovered in one day from a regenerative heat exchanger designed for a 140°F temperature drop? If energy costs \$3 per 10^6 Btu, what is the value of the recovered energy?

$$\text{Water removed from wood} = \frac{5\text{x}2000}{1+\frac{80}{100}} \times \frac{80-5}{100} = 4{,}167 \text{ lb/hr}$$

Water vapor through stacks = 4,167 × 0.9 = 3,750 lb/hr

Δh_r (at T_{db} = 290, T_{wb} = 190 and ΔT_r = 140 from Table 3) = 888 Btu/lb water

Total energy recovered in one day = 3,750 lb/hr × 888 Btu/lb × 24 hr/da = 0.80 × 10^8 Btu/da

$$\text{Energy savings per day} = \frac{0.80\times10^8 \text{ Btu/da} \times \$3}{10^6 \text{ Btu}} = \$240\text{/da}$$

Example B—Assuming that vent air at T_{db} of 270°F and T_{wb} of 180°F is passed through a regenerative heat exchanger, what is the percentage increase in energy recovery by increasing the ΔT_r from 100 to 120°F?

From fig. 7—Δh_r at ΔT_r = 100°F is 350 Btu/lb water

Δh_r at ΔT_r = 120°F is 750 Btu/lb water

$$\frac{750\text{-}350}{350} \times 100 = 114 \text{ percent}$$

II. Relation for finding W_1 above 1.0 lb water/lb dry air (Krischer 1956).

$$p_w = p_{wb} - 0.00529\left(1 - \frac{p_{wb}}{14.7}\right)\left(1 + \frac{T_{wb} - 32}{1800}\right)(T_{db} - T_{wb})$$

$$W_1 = \frac{0.622\ p_w}{14.7 - p_w}$$

where p_{wb} is the saturation pressure of water vapor at T_{wb} (Zimmerman and Lavine, 1964).

NOTATION

Δh_{air} =Change in enthalpy of dry air, Btu/lb dry air

Δh_{cond} =Change in enthalpy of condensate, Btu/lb water

Δh_r =Change in enthalpy of the vent air stream, recoverable energy in heat exchanger, Btu/lb water

Δh_{st} =Change in enthalpy of water vapor, Btu/lb water

p_w =partial pressure of water vapor at given T_{db} and T_{wb}, psi

p_{wb} =Saturation pressure of water vapor at T_{wb}, psi

T_1 =Vent air temperature into regenerative heat exchanger, °F

T_2 =Vent air temperature out of regenerative heat exchanger, °F

T_{db} =Dry bulb temperature, °F

T_{dp} =Dew point temperature, °F

T_{wb} =Wet bulb temperature, °F

T^*_{wb} =Wet bulb temperature corresponding to air at T_1 with dew point at T_2, °F

ΔT_r =Temperature drop of vent air across regenerative heat exchanger, °F

W =Humidity, lb water/lb dry air

W_1 =Vent air humidity into regenerative heat exchanger, lb water/lb dry air

W_2 =Vent air humidity out of regenerative heat exchanger, lb water/lb dry air

W_s =Saturation humidity at T_2, lb water/lb dry air

☆ U.S. Government Printing Office: 1979—667-165/335 Region No. 6

Rosen, Howard H.

1979. Potential for energy recovery from humid air streams. U.S. Dep. Agric. For. Serv., Res. Pap. NC-170, 10 p. U.S. Dep. Agric. For. Serv., North Cent. For. Exp. Stn., St. Paul, Minnesota.

The potential for energy recovery from the vent stream of dryers is examined by assuming the vent stream transfers its energy in a regenerative heat exchanger. Tables present energy recovery over a range of conditions. Example problems demonstrate the use of the energy recovery tables.

OXFORD: 536.722:536:423. KEY WORDS: dewpoint, wet bulb temperature, dry bulb temperature, enthalpy, heat exchanger, humidity, psychrometry.

Rosen, Howard H.

1979. Potential for energy recovery from humid air streams. U.S. Dep. Agric. For. Serv., Res. Pap. NC-170, 10 p. U.S. Dep. Agric. For. Serv., North Cent. For. Exp. Stn., St. Paul, Minnesota.

The potential for energy recovery from the vent stream of dryers is examined by assuming the vent stream transfers its energy in a regenerative heat exchanger. Tables present energy recovery over a range of conditions. Example problems demonstrate the use of the energy recovery tables.

OXFORD: 536.722:536:423. KEY WORDS: dewpoint, wet bulb temperature, dry bulb temperature, enthalpy, heat exchanger, humidity, psychrometry.

For recycling: Recycle your paper
Recycle your bottles
Recycle aluminum cans