Table B.5 —Aluminum tubular bus—schedule 80 ac ampacity (53.0% conductivity)

Size		Wall	Emissivity = 0.20, with sun temperature rise above 40 °C ambient							Emissivity = 0.20, without sun temperature rise above 40 °C ambient						
SPS	**OD**	**thickness**	**30**	**40**	**50**	**60**	**70**	**90**	**110**	**30**	**40**	**50**	**60**	**70**	**90**	**110**
(in)	**(in)**	**(in)**														
1.0	1.315	0.179	672	783	875	956	1027	1149	1253	726	828	915	991	1059	1177	1277
1.5	1.900	0.200	967	1131	1267	1385	1490	1671	1825	1056	1205	1332	1444	1543	1716	1864
2.0	2.375	0.218	1212	1420	1595	1745	1879	2110	2306	1334	1523	1684	1825	1952	2172	2360
2.5	2.875	0.276	1580	1855	2086	2285	2462	2768	3029	1751	1999	2211	2397	2564	2855	3104
3.0	3.500	0.300	1930	2273	2559	2807	3028	3408	3733	2157	2463	2725	2955	3161	3522	3832
3.5	4.000	0.318	2210	2608	2940	3228	3483	3925	4303	2484	2838	3140	3406	3645	4062	4422
4.0	4.500	0.337	2499	2954	3334	3663	3955	4460	4893	2824	3226	3570	3873	4146	4622	5034
5.0	5.563	0.375	3104	3683	4165	4583	4954	5598	6150	3544	4050	4484	4867	5212	5816	6340
6.0	6.625	0.432	3801	4525	5127	5649	6113	6919	7610	4379	5007	5546	6022	6450	7204	7859
8.0	8.625	0.500	4927	5898	6706	7407	8031	9118	10 056	5761	6592	7308	7943	8516	9528	10 413
Size		**Wall**	**Emissivity = 0.50, with sun temperature rise above 40 °C ambient**							**Emissivity = 0.50, without sun temperature rise above 40 °C ambient**						
SPS	**OD**	**thickness**	**30**	**40**	**50**	**60**	**70**	**90**	**110**	**30**	**40**	**50**	**60**	**70**	**90**	**110**
(in)	**(in)**	**(in)**														
1.0	1.315	0.179	650	785	896	992	1078	1226	1353	780	893	989	1075	1152	1289	1408
1.5	1.900	0.200	930	1134	1302	1446	1575	1798	1990	1146	1312	1455	1582	1697	1901	2079
2.0	2.375	0.218	1161	1425	1642	1829	1994	2282	2531	1457	1669	1851	2014	2161	2422	2652
2.5	2.875	0.276	1507	1862	2152	2402	2624	3009	3343	1923	2203	2445	2661	2856	3204	3512
3.0	3.500	0.300	1833	2282	2647	2961	3240	3725	4146	2382	2731	3032	3301	3545	3981	4366
3.5	4.000	0.318	2092	2619	3046	3413	3739	4307	4799	2756	3160	3510	3822	4106	4613	5063
4.0	4.500	0.337	2358	2967	3459	3882	4257	4911	5479	3144	3606	4006	4364	4690	5272	5789
5.0	5.563	0.375	2912	3700	4335	4879	5362	6204	6937	3974	4560	5069	5525	5941	6687	7352
6.0	6.625	0.432	3547	4548	5350	6037	6647	7711	8638	4940	5672	6309	6880	7401	8339	9178
8.0	8.625	0.500	4556	5931	7028	7965	8797	10 252	11 526	6561	7541	8396	9166	9871	11 145	12 293

Table B.6 —Single aluminum angle bus ac ampacity (55.0% conductivity)

	Emissivity = 0.20, with sun temperature rise above 40 °C ambient							Emissivity = 0.20, without sun temperature rise above 40 °C ambient						
Size (in)	**30**	**40**	**50**	**60**	**70**	**90**	**110**	**30**	**40**	**50**	**60**	**70**	**90**	**110**
3.250 by 3.250 by 0.250	1588	1857	2083	2279	2454	2757	3016	1734	1980	2191	2376	2542	2831	3081
4.000 by 4.000 by 0.250	1835	2153	2420	2652	2859	3217	3525	2022	2311	2557	2775	2970	3312	3608
4.000 by 4.000 by 0.375	2178	2557	2875	3153	3400	3831	4201	2401	2744	3039	3299	3533	3943	4300
4.500 by 4.500 by 0.375	2343	2757	3104	3408	3678	4150	4558	2597	2970	3291	3574	3829	4279	4670
5.000 by 5.000 by 0.375	2518	2969	3347	3677	3972	4488	4934	2806	3210	3557	3865	4143	4633	5061
	Emissivity = 0.50, with sun temperature rise above 40 °C ambient							**Emissivity = 0.50, without sun temperature rise above 40 °C ambient**						
Size (in)	**30**	**40**	**50**	**60**	**70**	**90**	**110**	**30**	**40**	**50**	**60**	**70**	**90**	**110**
3.250 by 3.250 by 0.250	1550	1889	2169	2412	2628	3007	3336	1902	2180	2420	2634	2828	3174	3481
4.000 by 4.000 by 0.250	1786	2194	2530	2821	3080	3535	3931	2236	2564	2848	3102	3334	3747	4114
4.000 by 4.000 by 0.375	2120	2606	3007	3354	3664	4208	4685	2654	3045	3385	3688	3965	4461	4904
4.500 by 4.500 by 0.375	2277	2813	3254	3637	3979	4580	5108	2885	3312	3683	4016	4320	4866	5356
5.000 by 5.000 by 0.375	2443	3032	3516	3936	4311	4973	5555	3130	3595	4000	4363	4696	5295	5833

Table B.7 —Double aluminium angle bus ac ampacity (55.0% conductivity)

	Emissivity = 0.20, with sun temperature rise above 40 °C ambient							Emissivity = 0.20, without sun temperature rise above 40 °C ambient						
Size (in)	**30**	**40**	**50**	**60**	**70**	**90**	**110**	**30**	**40**	**50**	**60**	**70**	**90**	**110**
3.250 by 3.250 by 0.250	2875	3370	3794	4166	4501	5086	5590	3045	3513	3917	4276	4600	5170	5663
4.000 by 4.000 by 0.250	3361	3949	4451	4892	5289	5984	6583	3579	4131	4608	5032	5415	6090	6675
4.000 by 4.000 by 0.375	3952	4646	5240	5764	6236	7065	7784	4208	4860	5426	5929	6385	7191	7893
4.500 by 4.500 by 0.375	4340	5109	5766	6346	6868	7786	8581	4636	5356	5980	6536	7040	7930	8707
5.000 by 5.000 by 0.375	4739	5585	6307	6945	7519	8528	9403	5077	5866	6552	7162	7715	8693	9546
	Emissivity = 0.50, with sun temperature rise above 40 °C ambient							**Emissivity = 0.50, without sun temperature rise above 40 °C ambient**						
Size (in)	**30**	**40**	**50**	**60**	**70**	**90**	**110**	**30**	**40**	**50**	**60**	**70**	**90**	**110**
3.250 by 3.250 by 0.250	2832	3407	3893	4318	4700	5370	5953	3247	3749	4187	4578	4933	5566	6122
4.000 by 4.000 by 0.250	3306	3996	4577	5086	5542	6345	7044	3835	4432	4952	5416	5839	6593	7258
4.000 by 4.000 by 0.375	3887	4702	5389	5992	6535	7492	8329	4510	5215	5830	6382	6885	7785	8582
4.500 by 4.500 by 0.375	4265	5173	5938	6609	7213	8277	9209	4983	5764	6446	7057	7615	8614	9499
5.000 by 5.000 by 0.375	4653	5658	6503	7245	7911	9087	10 117	5472	6331	7081	7755	8369	9470	10 447

Table B.8 —Aluminium integral web channel bus ac ampacity (55.0% conductivity)

	Emissivity = 0.20, with sun temperature rise above 40 °C ambient							Emissivity = 0.20, without sun temperature rise above 40 °C ambient						
Size	**30**	**40**	**50**	**60**	**70**	**90**	**110**	**30**	**40**	**50**	**60**	**70**	**90**	**110**
(in)														
4.000 by 4.000 by 0.250	2395	2948	3404	3799	4150	4761	5286	2949	3402	3795	4144	4461	5022	551
4.000 by 4.000 by 0.312	2603	3206	3703	4134	4517	5183	5757	3213	3706	4133	4514	4860	5472	600
6.000 by 4.000 by 0.375	3391	4168	4812	5370	5867	6734	7483	4161	4800	5356	5851	6301	7099	779
6.000 by 5.000 by 0.375	3558	4420	5129	5743	6289	7241	8062	4483	5175	5778	6316	6805	7674	843
6.000 by 6.000 by 0.550	4287	5335	6200	6950	7621	8795	9816	5412	6254	6990	7649	8250	9325	1027
8.000 by 5.000 by 0.500	4617	5695	6588	7365	8058	9272	10 326	5699	6582	7351	8039	8666	9783	1077
8.000 by 8.000 by 0.500	5849	7228	8375	9374	10 271	11 846	13 223	7212	8345	9335	10 224	11 036	12 491	1378
12.00 by 12.00 by 0.625	8610	10 614	12 296	13 774	15 108	17 477	19 574	10 466	12 138	13 608	14 936	16 156	18 361	2034
	Emissivity = 0.50, with sun temperature rise above 40 °C ambient							**Emissivity = 0.50, without sun temperature rise above 40 °C ambient**						
Size	**30**	**40**	**50**	**60**	**70**	**90**	**110**	**30**	**40**	**50**	**60**	**70**	**90**	**110**
(in)														
4.000 by 4.000 by 0.250	2463	3102	3627	4081	4486	5198	5819	3208	3707	4143	4535	4894	5538	611
4.000 by 4.000 by 0.312	2677	3376	3948	4444	4887	5665	6345	3497	4041	4517	4944	5336	6039	666
6.000 by 4.000 by 0.375	3572	4470	5211	5856	6434	7453	8349	4568	5280	5905	6467	6982	7911	874
6.000 by 5.000 by 0.375	3718	4722	5544	6256	6893	8014	8999	4929	5701	6379	6990	7551	8563	947
6.000 by 6.000 by 0.550	4403	5646	6661	7540	8329	9722	10 954	5963	6904	7733	8483	9174	10 428	1156
8.000 by 5.000 by 0.500	4886	6145	7185	8091	8906	10 347	11 622	6308	7300	8172	8960	9685	10 999	1218
8.000 by 8.000 by 0.500	5922	7594	8963	10 152	11 219	13 110	14 786	7990	9262	10 384	11 400	12 338	14 044	1559
12.00 by 12.00 by 0.625	8584	11 093	13 153	14 949	16 570	19 463	22 058	11 724	13 621	15 304	16 839	18 264	20 878	2327

Table B.9 —Single copper rectangular bar ac ampacity, with sun (99.0% conductivity)

	Emissivity = 0.35 temperature rise above 40 °C ambient							Emissivity = 0.85 temperature rise above 40 °C ambient						
Size (in)	**30**	**40**	**50**	**60**	**70**	**90**	**110**	**30**	**40**	**50**	**60**	**70**	**90**	**110**
0.250 by 4.000	1516	1751	1951	2127	2286	2564	2806	1661	1948	2194	2412	2611	2965	3281
0.250 by 5.000	1764	2040	2276	2484	2671	3002	3291	1955	2296	2589	2850	3088	3515	3898
0.250 by 6.000	2010	2327	2599	2838	3054	3437	3773	2250	2646	2987	3290	3568	4067	4517
0.375 by 4.000	1824	2112	2356	2572	2766	3107	3405	1985	2337	2638	2906	3149	3584	3973
0.375 by 5.000	2122	2458	2746	3000	3229	3633	3988	2337	2754	3112	3430	3721	4243	4712
0.375 by 6.000	2407	2792	3121	3412	3675	4141	4552	2679	3159	3573	3942	4279	4887	5436
0.375 by 8.000	2934	3409	3816	4178	4505	5089	5608	3319	3922	4442	4908	5335	6109	6813
0.500 by 4.000	2083	2415	2699	2948	3173	3569	3915	2253	2662	3011	3321	3603	4108	4560
0.500 by 5.000	2404	2790	3120	3412	3675	4141	4551	2633	3113	3524	3890	4224	4826	5367
0.500 by 6.000	2717	3156	3532	3865	4166	4701	5174	3007	3558	4031	4453	4839	5536	6167
0.500 by 8.000	3312	3853	4317	4730	5105	5774	6369	3729	4417	5011	5542	6030	6916	7723
0.625 by 4.000	2253	2617	2928	3203	3451	3889	4274	2423	2873	3258	3599	3911	4469	4971
0.625 by 5.000	2619	3045	3409	3731	4023	4540	4996	2854	3384	3840	4245	4615	5282	5885
0.625 by 6.000	2951	3433	3847	4213	4546	5137	5662	3251	3857	4378	4843	5269	6040	6739
0.625 by 8.000	3598	4192	4702	5156	5568	6306	6966	4034	4791	5443	6028	6565	7541	8433
0.625 by 10.000	4179	4875	5474	6009	6496	7372	8158	4752	5648	6424	7121	7763	8936	10 012
0.625 by 12.000	4758	5555	6244	6860	7422	8435	9348	5474	6511	7411	8222	8970	10 339	11 601
0.750 by 4.000	2455	2857	3199	3502	3775	4258	4683	2626	3125	3550	3928	4271	4888	5443
0.750 by 5.000	2834	3300	3699	4051	4370	4937	5438	3073	3656	4155	4599	5005	5737	6398
0.750 by 6.000	3204	3732	4185	4587	4951	5600	6177	3513	4179	4752	5262	5729	6575	7343
0.750 by 8.000	3881	4527	5082	5576	6026	6831	7551	4334	5159	5870	6507	7092	8157	9130
0.750 by 10.000	4509	5265	5917	6498	7029	7982	8840	5109	6085	6929	7687	8386	9662	10 835
0.750 by 12.000	5119	5983	6729	7396	8006	9107	10 100	5869	6995	7971	8850	9661	11 147	12 519

Table B.10—Single copper rectangular bar ac ampacity, without sun (99.0% conductivity)

	Emissivity = 0.35 temperature rise above 40 °C ambient							Emissivity = 0.85 temperature rise above 40 °C ambient						
Size (in)	**30**	**40**	**50**	**60**	**70**	**90**	**110**	**30**	**40**	**50**	**60**	**70**	**90**	**110**
0.250 by 4.000	1577	1802	1996	2168	2322	2595	2833	1793	2059	2290	2498	2688	3030	3337
0.250 by 5.000	1838	2102	2330	2533	2715	3039	3323	2114	2429	2705	2953	3180	3592	3965
0.250 by 6.000	2098	2401	2663	2896	3107	3481	3811	2436	2801	3121	3410	3675	4157	4595
0.375 by 4.000	1908	2182	2418	2627	2816	3150	3442	2167	2489	2770	3023	3254	3672	4049
0.375 by 5.000	2221	2542	2819	3065	3288	3683	4032	2550	2932	3266	3568	3844	4347	4802
0.375 by 6.000	2522	2889	3206	3488	3744	4199	4603	2924	3364	3751	4099	4421	5006	5539
0.375 by 8.000	3081	3532	3924	4274	4593	5164	5673	3628	4179	4665	5105	5513	6258	6941
0.500 by 4.000	2189	2505	2777	3018	3236	3623	3962	2485	2855	3179	3470	3737	4221	4658
0.500 by 5.000	2527	2894	3211	3493	3749	4204	4606	2900	3335	3717	4062	4379	4956	5480
0.500 by 6.000	2858	3275	3636	3958	4251	4773	5237	3310	3810	4250	4647	5014	5683	6294
0.500 by 8.000	3489	4002	4448	4847	5211	5863	6447	4103	4729	5281	5782	6246	7097	7879
0.625 by 4.000	2379	2724	3021	3286	3526	3953	4330	2700	3104	3458	3778	4071	4604	5088
0.625 by 5.000	2765	3168	3517	3828	4111	4615	5062	3171	3650	4069	4449	4799	5437	6019
0.625 by 6.000	3117	3573	3969	4323	4645	5222	5736	3607	4154	4636	5072	5475	6213	6889
0.625 by 8.000	3804	4365	4854	5291	5691	6411	7057	4469	5153	5757	6307	6816	7752	8615
0.625 by 10.000	4423	5081	5654	6169	6642	7496	8266	5262	6073	6792	7448	8057	9182	10 225
0.625 by 12.000	5042	5795	6454	7046	7591	8578	9473	6060	7000	7835	8597	9308	10 622	11 845
0.750 by 4.000	2605	2983	3310	3601	3865	4335	4750	2956	3400	3789	4139	4462	5049	5582
0.750 by 5.000	3006	3445	3825	4164	4473	5024	5515	3446	3967	4425	4839	5221	5918	6555
0.750 by 6.000	3397	3895	4328	4715	5067	5699	6263	3929	4526	5052	5529	5970	6778	7518
0.750 by 8.000	4117	4726	5256	5732	6167	6951	7655	4834	5575	6231	6827	7381	8399	9340
0.750 by 10.000	4787	5499	6122	6681	7195	8123	8963	5690	6569	7348	8059	8721	9944	11 078
0.750 by 12.000	5439	6253	6965	7607	8198	9269	10 242	6532	7547	8449	9273	10 043	11 468	12 795

Table B.11—Copper tubular bus—schedule 40 ac ampacity (99.0% conductivity)

Size		**Wall**	Emissivity = 0.35, with sun temperature rise above 40 °C ambient							Emissivity = 0.35, without sun temperature rise above 40°C ambient						
SPS	**OD**	**thickness**	**30**	**40**	**50**	**60**	**70**	**90**	**110**	**30**	**40**	**50**	**60**	**70**	**90**	**110**
(in)	**(in)**	**(in)**														
1.0	1.315	0.127	771	912	1029	1131	1220	1375	1506	878	1002	1107	1200	1283	1428	1552
1.5	1.900	0.150	1131	1347	1526	1681	1818	2054	2255	1313	1499	1658	1798	1923	2143	2332
2.0	2.375	0.157	1383	1656	1881	2075	2246	2543	2796	1628	1859	2056	2231	2387	2661	2899
2.5	2.875	0.188	1755	2111	2403	2655	2878	3264	3594	2091	2389	2644	2868	3071	3426	3734
3.0	3.500	0.219	2214	2675	3054	3380	3669	4169	4597	2673	3054	3381	3670	3930	4388	4787
4.0	4.500	0.250	2870	3492	4002	4441	4829	5502	6080	3530	4035	4470	4855	5202	5815	6350
6.0	6.625	0.250	3903	4807	5544	6177	6737	7708	8545	4955	5669	6285	6831	7324	8199	8968
8.0	8.625	0.313	5281	6570	7617	8514	9308	10 687	11 880	6871	7868	8728	9493	10 187	11 422	12 512
Size		**Wall**	Emissivity = 0.85, with sun temperature rise above 40 °C ambient							Emissivity = 0.85, without sun temperature rise above 40 °C ambient						
SPS	**OD**	**thickness**	**30**	**40**	**50**	**60**	**70**	**90**	**110**	**30**	**40**	**50**	**60**	**70**	**90**	**110**
(in)	**(in)**	**(in)**														
1.0	1.315	0.127	726	916	1069	1199	1315	1515	1688	978	1120	1243	1353	1452	1629	1786
1.5	1.900	0.150	1054	1354	1593	1797	1977	2289	2559	1482	1698	1886	2054	2206	2479	2722
2.0	2.375	0.157	1279	1665	1970	2230	2458	2855	3200	1851	2122	2358	2569	2762	3106	3414
2.5	2.875	0.188	1611	2123	2526	2867	3168	3689	4142	2394	2747	3054	3328	3579	4030	4433
3.0	3.500	0.219	2014	2692	3221	3668	4062	4745	5339	3083	3539	3936	4292	4618	5204	5729
4.0	4.500	0.250	2579	3517	4242	4852	5389	6321	7131	4112	4723	5256	5736	6175	6968	7682
6.0	6.625	0.250	3425	4848	5925	6827	7617	8988	10 182	5863	6741	7509	8201	8836	9988	11 031
8.0	8.625	0.313	4543	6632	8190	9488	10 624	12 596	14 315	8220	9459	10 545	11 527	12 431	14 075	15 569

Table B.12—Copper tubular bus—schedule 80 ac ampacity (99.0% conductivity)

Size		Wall	Emissivity = 0.35, with sun temperature rise above 40 °C ambient							Emissivity = 0.35, without sun temperature rise above 40 °C ambient						
SPS	OD	Thickness	30	40	50	60	70	90	110	30	40	50	60	70	90	110
(in)	(in)	(in)														
1.0	1.315	0.182	903	1069	1206	1325	1430	1611	1765	1029	1174	1297	1406	1503	1673	1818
1.5	1.900	0.203	1289	1536	1741	1917	2073	2343	2573	1498	1710	1891	2051	2194	2445	2661
2.0	2.375	0.221	1610	1928	2190	2416	2616	2962	3258	1895	2164	2395	2598	2780	3100	3377
2.5	2.875	0.280	2093	2517	2866	3168	3434	3896	4292	2493	2848	3153	3422	3664	4089	4459
3.0	3.500	0.304	2536	3065	3501	3876	4209	4785	5279	3062	3500	3876	4209	4508	5036	5497
4.0	4.500	0.341	3256	3963	4543	5043	5486	6255	6917	4004	4580	5075	5513	5910	6610	7224
6.0	6.625	0.437	4789	5906	6820	7606	8306	9525	10 584	6081	6965	7730	8411	9030	10 132	11 108
8.0	8.625	0.500	6076	7571	8790	9841	10 776	12 412	13 842	7906	9066	10 073	10 973	11 794	13 265	14 579
Size		Wall	Emissivity = 0.85, with sun temperature rise above 40 °C ambient							Emissivity = 0.85, without sun temperature rise above 40 °C ambient						
SPS	OD	Thickness	30	40	50	60	70	90	110	30	40	50	60	70	90	110
(in)	(in)	(in)														
1.0	1.315	0.182	851	1073	1252	1405	1540	1775	1978	1146	1313	1457	1585	1701	1909	2092
1.5	1.900	0.203	1202	1544	1817	2050	2255	2612	2920	1690	1937	2151	2343	2517	2829	3106
2.0	2.375	0.221	1489	1938	2294	2597	2863	3326	3728	2155	2471	2746	2992	3216	3619	3978
2.5	2.875	0.280	1921	2532	3013	3420	3780	4404	4946	2855	3276	3642	3971	4271	4810	5293
3.0	3.500	0.304	2308	3086	3693	4207	4659	5446	6130	3532	4056	4512	4922	5296	5972	6579
4.0	4.500	0.341	2926	3992	4816	5511	6122	7186	8113	4664	5360	5967	6513	7015	7921	8739
6.0	6.625	0.437	4203	5956	7288	8407	9391	11 107	12 612	7195	8282	9236	10 099	10 894	12 343	13 664
8.0	8.625	0.500	5277	7642	9452	10 967	12 300	14 629	16 679	9457	10 899	12 170	13 324	14 391	16 346	18 140

Table B.13—Double copper channel bus ac ampacity (99% conductivity)

	Emissivity = 0.35, with sun temperature rise above 40 °C ambient							Emissivity = 0.35, without sun temperature rise above 40 °C ambient						
Size (in)	30	40	50	60	70	90	110	30	40	50	60	70	90	110
3.000 by 1.313 by 0.216	2785	3347	3819	4232	4601	5246	5801	3178	3671	4098	4478	4822	5430	5961
4.000 by 1.750 by 0.240	3697	4470	5118	5684	6190	7075	7841	4283	4951	5531	6048	6517	7348	8076
4.000 by 1.750 by 0.338	4106	4969	5695	6331	6902	7906	8780	4757	5504	6155	6737	7267	8212	9044
5.000 by 2.188 by 0.338	4967	6040	6942	7731	8440	9686	10 772	5827	6746	7548	8266	8920	10 087	11 117
6.000 by 2.688 by 0.384	5932	7235	8332	9293	10 159	11 686	13 025	6995	8107	9079	9953	10 751	12 182	13 453
	Emissivity = 0.85, with sun temperature rise above 40 °C ambient							Emissivity = 0.85, without sun temperature rise above 40 °C ambient						
Size (in)	30	40	50	60	70	90	110	30	40	50	60	70	90	110
3.000 by 1.313 by 0.216	2733	3430	4003	4499	4941	5718	6395	3504	4053	4533	4963	5356	6061	6689
4.000 by 1.750 by 0.240	3619	4593	5390	6078	6693	7772	8714	4764	5514	6171	6762	7303	8276	9145
4.000 by 1.750 by 0.338	4019	5106	5998	6771	7464	8685	9759	5290	6129	6867	7532	8143	9248	10 241
5.000 by 2.188 by 0.338	4851	6222	7341	8310	9177	10 706	12 052	6526	7565	8480	9306	10 065	11 440	12 680
6.000 by 2.688 by 0.384	5770	7460	8836	10 029	11 099	12 990	14 663	7888	9154	10 271	11 283	12 217	13 915	15 455

Annex C

(informative)

Thermal considerations for outdoor bus-conductor design

C.1 Abstract

The current rating of both the outdoor rigid bus conductor and the strain bus conductor is based on several limiting criteria. This annex brings to a single source the thermal considerations of both the rigid bus and the strain conductor, namely, the heat transfer and properties of material. Historically, thermal designs have been conservative. This annex will allow the engineer to reexamine the factors involved in increased current loadings of the rigid bus and strain bus conductor and possibly to determine new thermal limits.

The material in this annex is mostly from the paper, "Thermal considerations for outdoor bus-conductor design," by the Substation Committee of the IEEE Power Engineering Society.[37] However, some equations have been corrected and/or updated, and relevant additional material has also been added.

NOTE—The English units used in the original paper have been converted to the SI system in this annex.

C.2 Introduction

Thermal considerations entering into the design of bus conductors for outdoor substations fall into two general categories, heat transfer and properties of materials. Each of these subjects will be considered in detail in this annex. The first, heat transfer to and from the conductor, is relatively independent of the material and is mainly a function of the geometry of the conductor, proximity to other surfaces or conductors, atmospheric conditions, and geographic location. The most important element in the computation is the estimate of forced convection arising from wind currents. A method is given here to compute heat losses due to forced and natural convection and radiation and heat gained from the sun. Using the formulas provided, it is possible to calculate the current-carrying capacity of any conductor corresponding to a given temperature rise. Examples are provided showing methods for calculating the ampacity of conventional types of bus conductors (e.g., bar, tube, channel, angle, and integral web).

The second subject, properties of materials, includes the effects of temperature and outdoor exposure on the mechanical strength, electrical resistivity, dimensional stability, and surface condition of the conductor. Aluminum alloys, copper, and copper alloys are included in the discussion and tabulations. No attempt has been made to consider the relative merits of the conductors. Instead, technical information is provided that must be coupled with economic factors when optimizing design and selecting materials.

[37]Published by *IEEE Transaction on Power Apparatus and Systems*, vol. PAS-95, no. 4, July/Aug. 1976. Paper F 76 205-5. Recommended and approved by the IEEE Substations Committee of the IEEE Power Engineering Society for presentation at the IEEE PES Winter Meeting & Tesla Symposium, New York, NY, January 25–30, 1976. Manuscript submitted October 31, 1975; made available for printing November 24, 1975.

C.3 Heat transfer

Usually more than half the heat generated by resistance losses in a bus conductor is removed from the surface by convection of the surrounding air. The remainder is given off by radiation from external surfaces. Unfortunately, it is not at all convenient to run controlled outdoor tests to determine the appropriate heat transfer coefficients. As a result, there is very little independent support for the formulas found in the literature.

A variety of formulas can be found for the sizes of conductors of interest. All show that convective heat transfer outdoors exceeds that in the indoors when it is assumed that the wind velocity is 0.6 m/s (2 ft/s). However, the difference between the indoor and outdoor rating is often not very great. If a slower wind velocity is assumed, then the outdoor heat losses may be calculated as lower than those indoors. This is not plausible. It is, therefore, concluded that assumption of a 0.6 m/s wind is a conservative, yet realistic, approach, and it will be used in the examples given herein.

The difference between indoor and outdoor convection losses are found to diminish with increasing conductor size and with increasing temperature rise. This is because an increase in the temperature rise leads to natural drafts, which can be as effective as a slight breeze in promoting heat transfer. Similarly, with large conductors, the assumed 0.6 m/s wind speed is so low as to add very little benefit over natural convection.

For the purpose of calculating ampacity, conditions that are the least advantageous for convection must be considered. Thus, it is assumed that there is only a 0.6 m/s wind. (See NOTE 1 following the references of this annex.) It is to be expected that when the flow is at an angle or normal to the surface, heat transfer will increase. Likewise, it is wise to stipulate that the emissivity is a low value when there is no solar heating. This will provide the most conservative ampacity rating. In contrast, when there can be considerable solar heating, a high value of emissivity essentially equal to solar absorptivity may give the most conservative ampacity rating.

In connection with this last point, it should be noted that solar heating of the conductor always diminishes ampacity and can result in outdoor current ratings that are lower than indoor ratings. This is less likely on smaller conductors for which forced (outdoor) convective heat transfer coefficients are relatively high. However, for large conductors with high absorptivity, the heat gain from solar radiation can exceed the improvement in convective heat transfer due to the wind effect, and ratings are reduced accordingly.

C.3.1 Assumptions

Some assumptions will be made about the properties of air in order to reduce the number of terms that should be carried through the computations. These approximations will have a negligible effect on the accuracy of the calculated ampacity. First, it is assumed that the properties of air are constant and may be evaluated at mid-range temperatures. This is reasonable because variations in heat capacity, conductivity, density, and viscosity of air tend to compensate for one another and have very little net effect on heat transfer over the temperature range of interest. For example, the Prandtl number of air:

$$\mathrm{Pr} = C_{pa}\frac{\mu_a}{k_a}$$

is commonly taken as 0.7 over a wide range of ordinary temperatures and pressures using the properties for air at 60 ^{o}C as follows:

$C_{\rho a}$	is the heat capacity of air = 1006 J/(kg ^{o}C)
μ_a	is the dynamic viscosity of air = 2.04 × 10^{-5} kg/(m s)
k_a	is the thermal conductivity of air = 0.0288 W/(m ^{o}C)

ρ_a is the density of air = 1.08 kg/m^3
$\nu_a = \mu_a/\rho_a$ is the kinematic viscosity of air = 18.9 × 10^{-6} m^2/s

As a result, only the temperature difference between the conductor and the surrounding air is important in calculating convective heat losses. For example, the convection losses calculated for a 40 °C temperature rise apply equally for a 70 °C conductor in 30 °C air or an 85 °C conductor in 45 °C air.

One might expect that the ampacities in the above instances would be different because the resistivities at 70 °C and 85 °C are different. However, it will be seen that the radiation losses that increase with the absolute temperature rather than the temperature difference tend to offset the rise in resistivities. As a result, ampacities based on the 40 °C ambient apply quite well to ambients from about 20 °C to 50 °C. Thus, for any temperature rise, there is a single ampacity (irrespective of the ambient), and it is usually not necessary to calculate a different ampacity for each ambient temperature and temperature rise.

C.3.2 Computation method

The general approach suggested for calculating the ampacity of any outdoor bus conductor is summarized below. A detailed explanation of each item follows.

Step by step, the procedure is as follows:

a) Identify all exterior surfaces that should be treated as flat planes subject to forced convection.

b) Identify any exterior surfaces that should be treated as cylindrical surfaces subject to forced convection.

c) Identify any surfaces that may be shielded from the wind and only lose heat via natural convection (the same as indoors).

d) Identify surfaces that will lose heat also by radiation.

e) Ascertain the orientation and location of the conductors in determining the projected area exposed to solar heat gain.

f) For each of the appropriate areas [items a), b), and c)], compute the total convective heat losses q_c.

g) For the appropriate values of emittance and area [item c)], compute the total heat lost through radiation, q_r.

h) Consider the projected area, latitude, altitude, seasonal factors, absorptivity, and so on, and compute the solar heat gain, q_s.

i) Sum the heat gain and loss terms, and for the appropriately temperature compensated values of resistance (R) and skin effect coefficient (F), compute ampacity using using Equation (C.1):

$$I = \sqrt{\frac{q_c + q_r - qs}{R F}} \tag{C.1}$$

where

I is the current for the allowable temperature rise, A
q_c is the convective heat loss, W/m
q_r is the radiation loss, W/m
q_s is the solar heat gain, W/m

R is the direct current resistance at the operating temperature, Ω/m
F is the skin effect coefficient for 60 H current

The following is an analysis of each operation. It will show that the basic equations can be reduced to easy-to-handle forms.

C.3.2.1 Forced convection over flat surfaces

When air flows parallel to and over a flat planar surface, Equation (C.2) may be used to calculate the heat transfer coefficient:

$$h = 0.664 \frac{k_a}{L} \mathrm{Re}^{1/2} \mathrm{Pr}^{1/3} \qquad \text{(C.2)}$$

where

h is the heat transfer coefficient, W/(m^2 °C)
k_a is the thermal conductivity of air, W/(m^2 °C)
L is the length of flow path over conductor (normally the width or thickness), m
Re is the Reynolds number, equal to $\frac{L\ V}{\nu_a}$
V is the air velocity, m/s

The total heat lost (in W/m) from the surface due to forced convection is given by Equation (C.3):

$$q_c = h\ A\ \Delta T \qquad \text{(C.3)}$$

where

q_c are the convection losses, W/m
A is the area of flat surfaces, m^2/linear m of conductor
ΔT is the temperature difference between the surface of the conductor (T_c) and the surrounding air (T_a), °C

At elevations above sea level multiply q_c by $P^{0.5}$ where P is the air pressure in atmospheres. This will reduce the convective coefficient for lower pressures.

For the properties of air noted earlier in C.3.1, q_c is given, using the variables defined above, by Equation (C.4):

$$q_c = 3.906 \times \sqrt{\frac{V}{L}}\ A\ \Delta T \qquad \text{(C.4)}$$