

Supplementary information

DEVELOPMENT OF A DYNAMIC INCENTIVE AND PENALTY PROGRAM FOR IMPROVING THE ENERGY PERFORMANCE OF EXISTING BUILDINGS

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Table S1. Seven grades for the operational and letter ratings in the building EPCs

Operational rating	Letter rating ("A to G" label)
0 to 25	A
26 to 50	B
51 to 75	C
76 to 100	D
101 to 125	E
126 to 150	F
More than 150	G

Note: The operational rating of the category benchmark is 100.

Table S2. Detailed descriptions of the four types of incentive programs

Classification	Assumption 1	Assumption 2	Assumptions 3 & 4
Type I-1	The operational rating of a given building is "below" 100 (i.e., incentive zone)	The operational rating of a given building is "less" than the average value of the operational ratings of the retrieved cases (i.e., incentive available)	The one-step higher operational and letter ratings than the grade of a given building (assumption 3) is "less" than the operational rating as the minimum criteria for achieving the national CERT (assumption 4)
Type I-2	The operational rating of a given building is "below" 100 (i.e., incentive zone)	The operational rating of a given building is "less" than the average value of the operational ratings of the retrieved cases (i.e., incentive available)	The one-step higher operational and letter ratings than the grade of a given building (assumption 3) is "more" than the operational rating as the minimum criteria for achieving the national CERT (assumption 4)
Type I-3	The operational rating of a given building is "below" 100 (i.e., incentive zone)	The operational rating of a given building is "more" than the average value of the operational ratings of the retrieved cases (i.e., incentive not available)	The one-step higher operational and letter ratings than the grade of a given building (assumption 3) is "less" than the operational rating as the minimum criteria for achieving the national CERT (assumption 4)
Type I-4	The operational rating of a given building is "below" 100 (i.e., incentive zone)	The operational rating of a given building is "more" than the average value of the operational ratings of the retrieved cases (i.e., incentive not available)	The one-step higher operational and letter ratings than the grade of a given building (assumption 3) is "more" than the operational rating as the minimum criteria for achieving the national CERT (assumption 4)

Table S3. Detailed descriptions of the four types of penalty programs

Classification	Assumption 1	Assumption 2	Assumptions 3 & 4
Type P-1	The operational rating of a given building is “over” 100 (i.e., penalty zone)	The operational rating of a given building is “less” than the average value of the operational ratings of the retrieved cases (i.e., penalty not available)	The one-step higher operational and letter ratings than the grade of a given building (assumption 3) is “less” than the operational rating as the minimum criteria for achieving the national <i>CERT</i> (assumption 4)
Type P-2	The operational rating of a given building is “over” 100 (i.e., penalty zone)	The operational rating of a given building is “less” than the average value of the operational ratings of the retrieved cases (i.e., penalty not available)	The one-step higher operational and letter ratings than the grade of a given building (assumption 3) is “more” than the operational rating as the minimum criteria for achieving the national <i>CERT</i> (assumption 4)
Type P-3	The operational rating of a given building is “over” 100 (i.e., penalty zone)	The operational rating of a given building is “more” than the average value of the operational ratings of the retrieved cases (i.e., penalty available)	The one-step higher operational and letter ratings than the grade of a given building (assumption 3) is “less” than the operational rating as the minimum criteria for achieving the national <i>CERT</i> (assumption 4)
Type P-4	The operational rating of a given building is “over” 100 (i.e., penalty zone)	The operational rating of a given building is “more” than the average value of the operational ratings of the retrieved cases (i.e., penalty available)	The one-step higher operational and letter ratings than the grade of a given building (assumption 3) is “more” than the operational rating as the minimum criteria for achieving the national <i>CERT</i> (assumption 4)

Table S4. Project characteristics of the five similar cases retrieved using the S-CBR model for the incentive programs

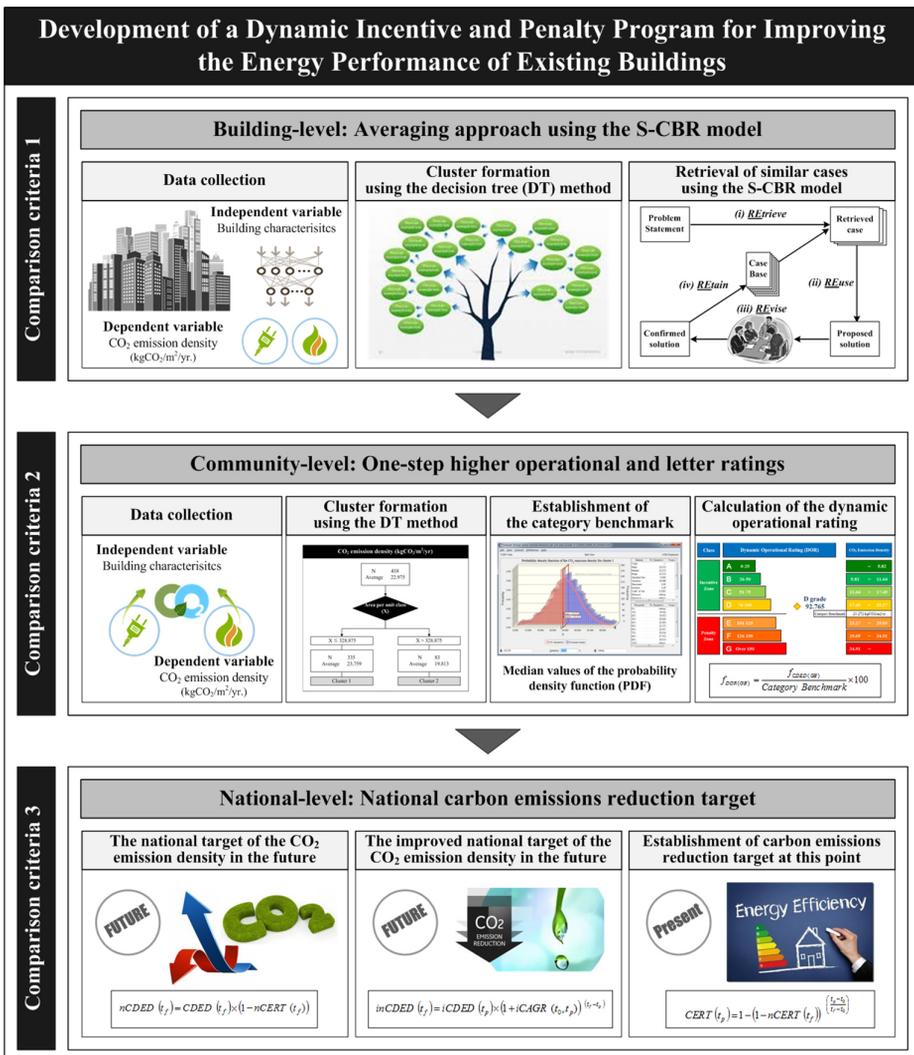
Class	No.	IV-1	IV-2	IV-3	IV-4	IV-5	IV-6	IV-7	IV-8	IV-9	IV-10	IV-11	IV-12	IV-13	IV-14	DV	OR	LR	CS	PA
TC	79	7	1	1	3	33	2,385	5	10,401	1,275	46	0.123	0.004	226.1	27.72	21.27	92.77	D	-	-
RC 1	281	21	1	2	3	38	2,674	5	8,793	1,260	46	0.143	0.005	191.2	27.40	24.80	108.19	E	81.3	83.4
RC 2	68	6	1	1	3	38	2,212	6	8,987	1,164	42	0.130	0.005	214.0	27.71	23.15	100.99	E	77.8	91.1
RC 3	127	10	1	1	1	22	2,772	4	10,834	1,241	43	0.115	0.004	252.0	28.86	23.55	102.72	D	76.8	89.3
RC 4	233	17	1	1	2	47	2,122	6	9,061	1,278	43	0.141	0.005	210.7	29.72	21.56	94.05	D	75.5	98.6
RC 5	227	17	1	2	2	27	2,282	4	7,780	1,245	43	0.160	0.006	180.9	28.95	24.31	106.05	E	75.3	85.7

Note: TC stands for the test case; RC stands for the retrieved case; IV-1 stands for administrative division; IV-2 stands for founder type; IV-3 stands for structure type; IV-4 stands for safety rating; IV-5 stands for elapsed years; IV-6 stands for building area; IV-7 stands for the number of stories; IV-8 stands for total floor area; IV-9 stands for the number of person; IV-10 stands for the number of classes; IV-11 stands for person per unit area; IV-12 stands for class per unit area; IV-13 stands for area per class; IV-14 stands for person per class; DV-1 stands for the CO₂ emission density; OR stands for the operational rating; LR stands for the letter rating; CS stands for the case similarity; and PA stands for the prediction accuracy.

Table S5. Project characteristics of the three similar cases retrieved using the S-CBR model for the penalty programs

Class	No.	IV-1	IV-2	IV-3	IV-4	IV-5	IV-6	IV-7	IV-8	IV-9	IV-10	IV-11	IV-12	IV-13	IV-14	DV	OR	LR	CS	PA
TC	307	18	1	1	3	27	1,530	3	4,710	550	22	0.118	0.005	214.1	25.00	29.89	132.78	F	-	-
RC 1	43	3	1	2	3	26	1,680	4	5,800	631	23	0.109	0.004	252.2	27.44	31.97	139.45	F	64.5	93.1
RC 2	68	5	1	2	1	27	1,355	4	3,923	495	18	0.126	0.005	217.9	27.50	34.33	149.74	F	64.0	85.2
RC 3	356	21	1	1	3	33	1,735	4	6,762	786	30	0.116	0.004	225.4	26.20	27.98	122.05	E	62.1	93.6

Note: TC stands for the test case; RC stands for the retrieved case; IV-1 stands for administrative division; IV-2 stands for founder type; IV-3 stands for structure type; IV-4 stands for safety rating; IV-5 stands for elapsed years; IV-6 stands for building area; IV-7 stands for the number of stories; IV-8 stands for total floor area; IV-9 stands for the number of person; IV-10 stands for the number of classes; IV-11 stands for person per unit area; IV-12 stands for class per unit area; IV-13 stands for area per class; IV-14 stands for person per class; DV stands for the CO₂ emission density; OR stands for the operational rating; LR stands for the letter rating; CS stands for the case similarity; and PA stands for the prediction accuracy.



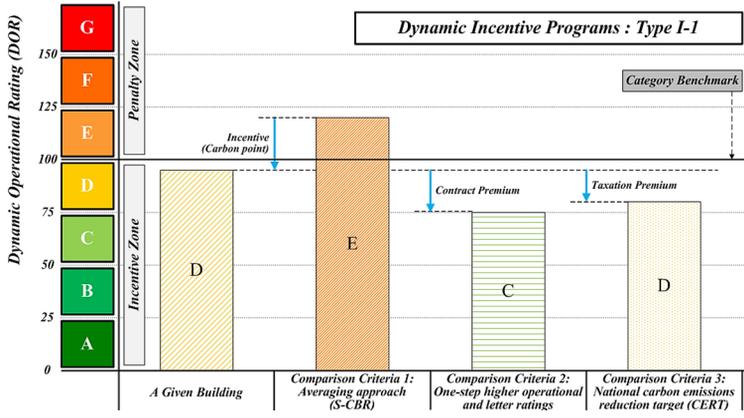


Fig. S2. Comparison chart for Type I-1 of incentive programs

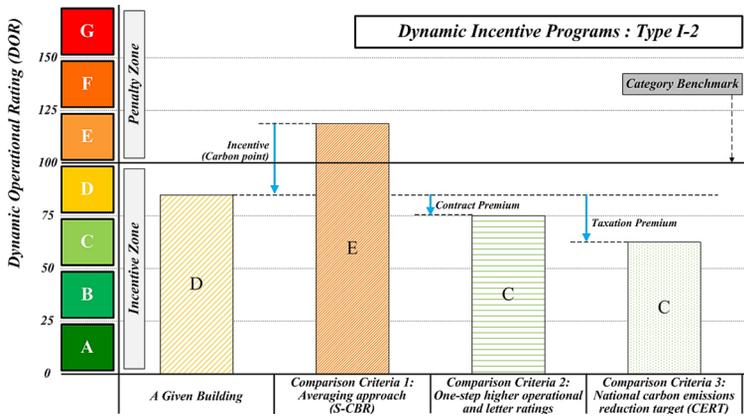


Fig. S3. Comparison chart for Type I-2 of incentive programs

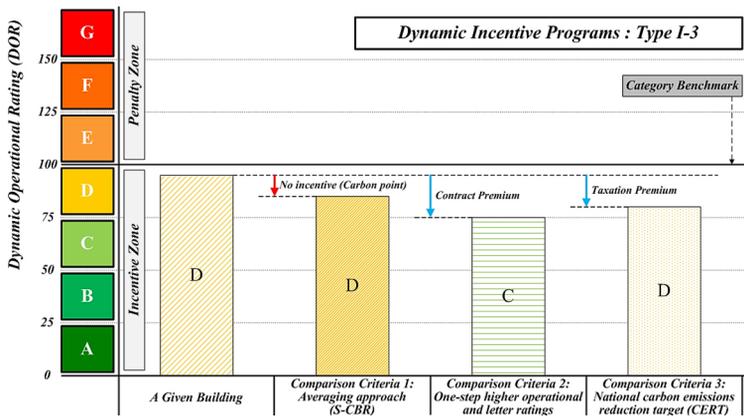


Fig. S4. Comparison chart for Type I-3 of incentive programs

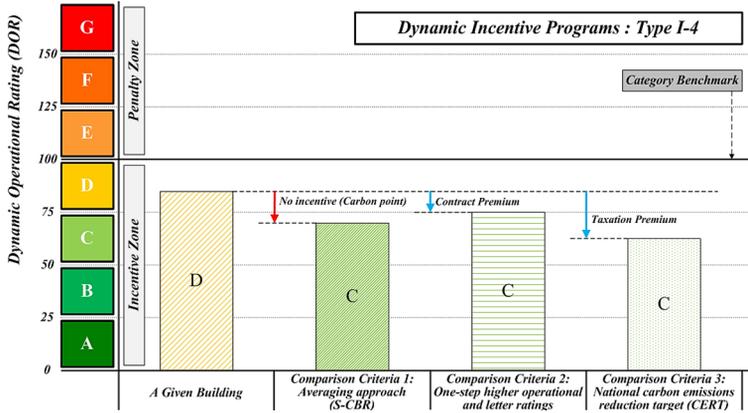


Fig. S5. Comparison chart for Type I-4 of incentive programs

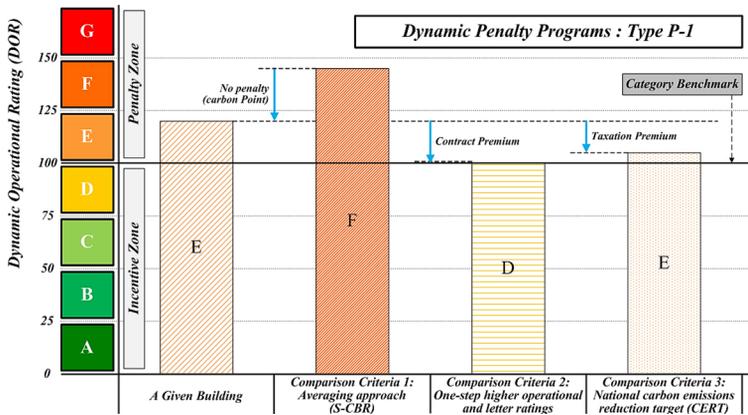


Fig. S6. Comparison chart for Type P-1 of the penalty programs

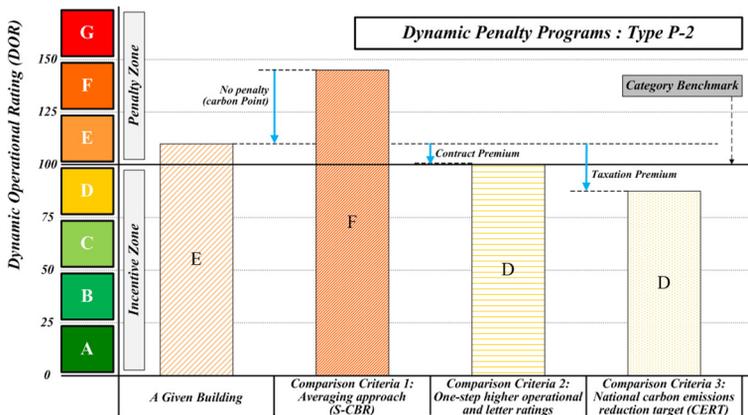


Fig. S7. Comparison chart for Type P-2 of the penalty programs

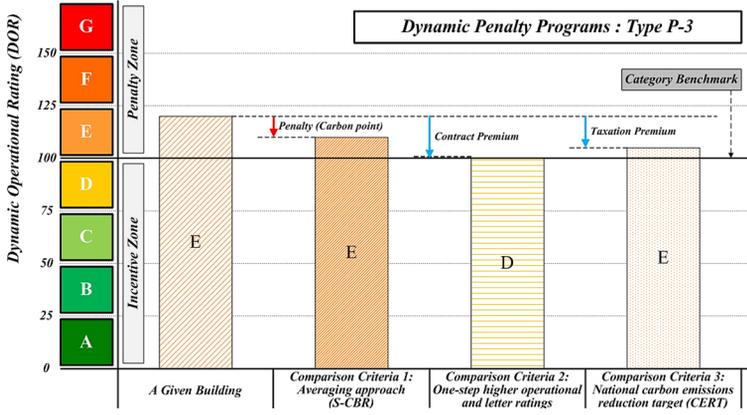


Fig. S8. Comparison chart for Type P-3 of the penalty programs

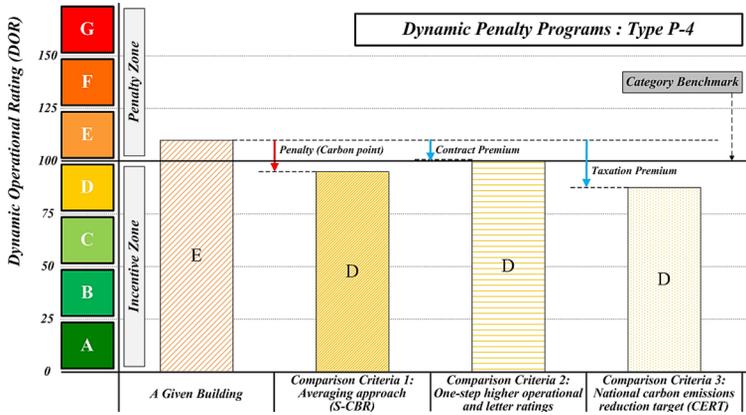


Fig. S9. Comparison chart for Type P-4 of the penalty programs

A Simplified Case-Based Reasoning (S-CBR) Model for Establishing the Building-level Comparison Criteria as the Averaging Approach

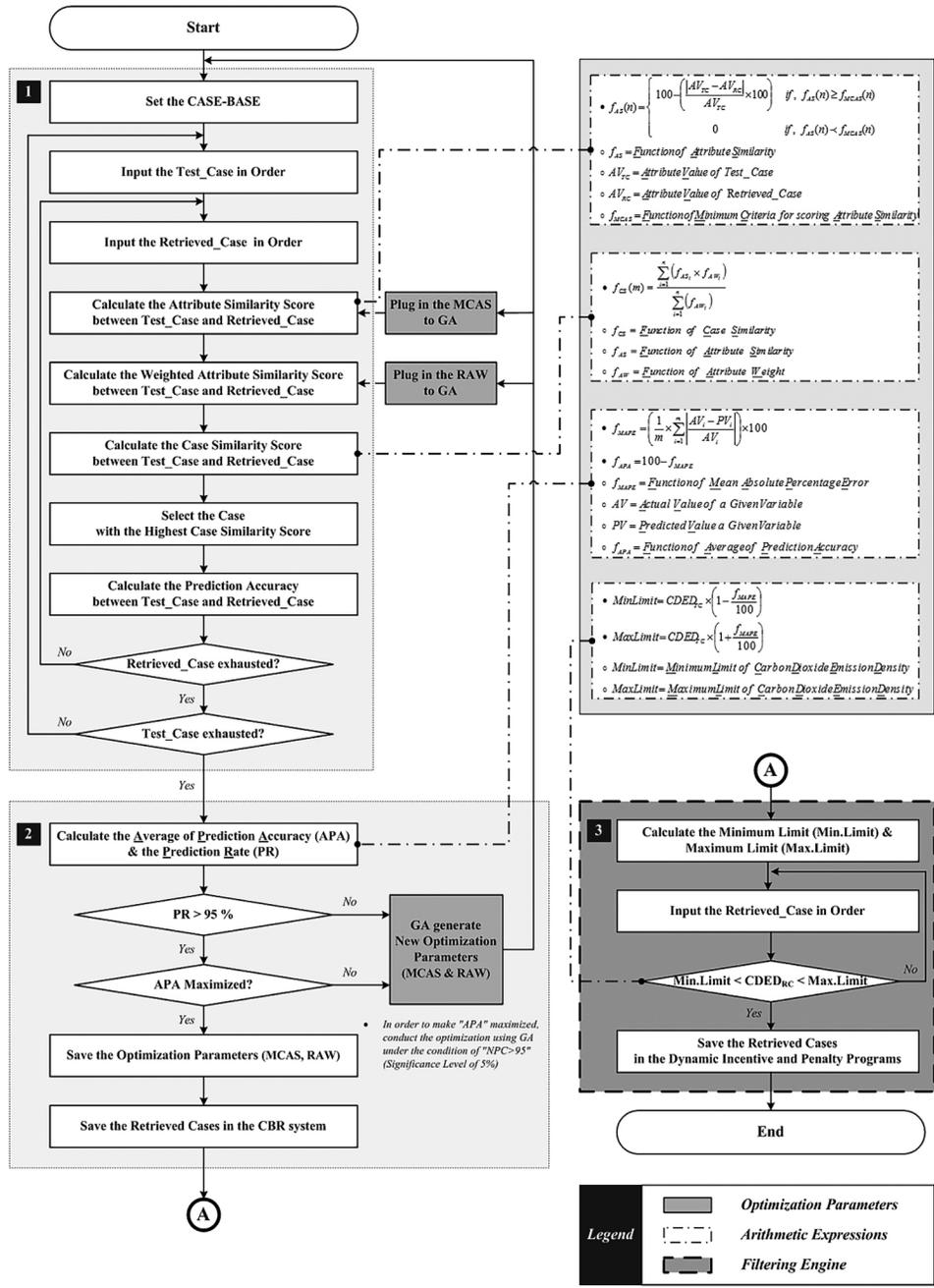


Fig. S10. Development process of a simplified case-based reasoning model

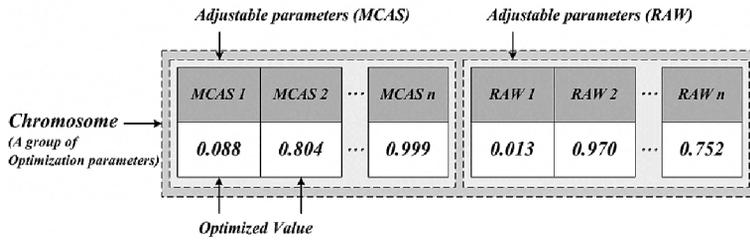


Fig. S11. Description of the adjustable parameters in the optimization process using GA

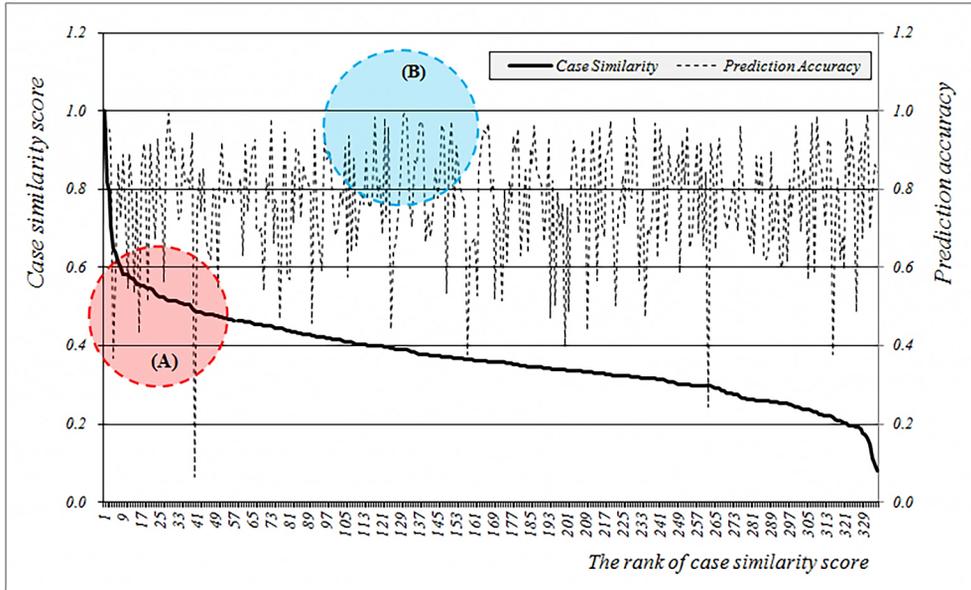


Fig. S12. Relationship between the case similarity and the prediction accuracy (e.g., cluster 1)

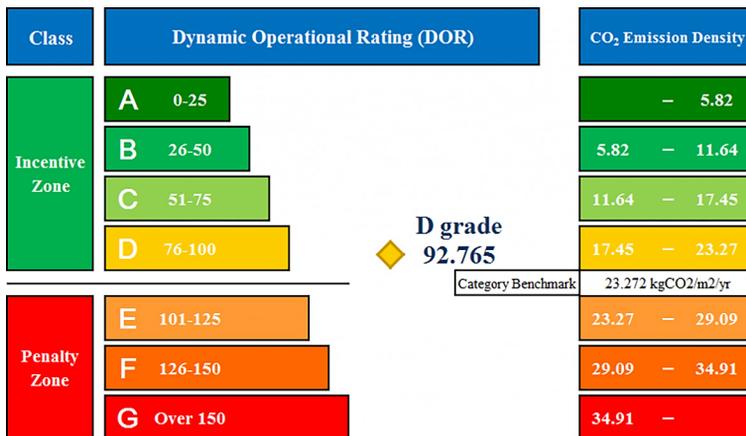


Fig. S13. Visual chart for the dynamic operational rating (e.g., cluster 1)

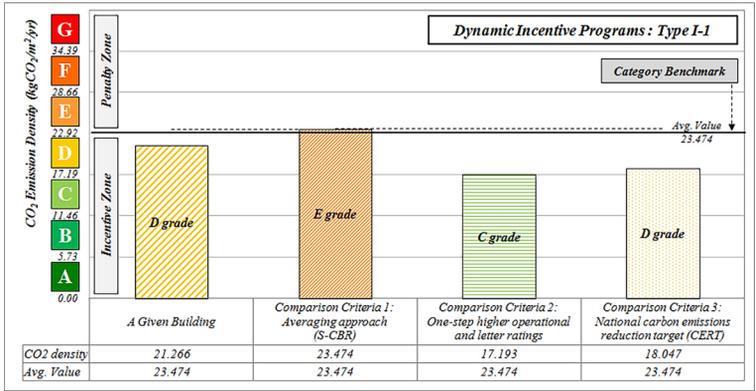


Fig. S14. Comparison chart for the incentive programs (actual CO2 emission density)

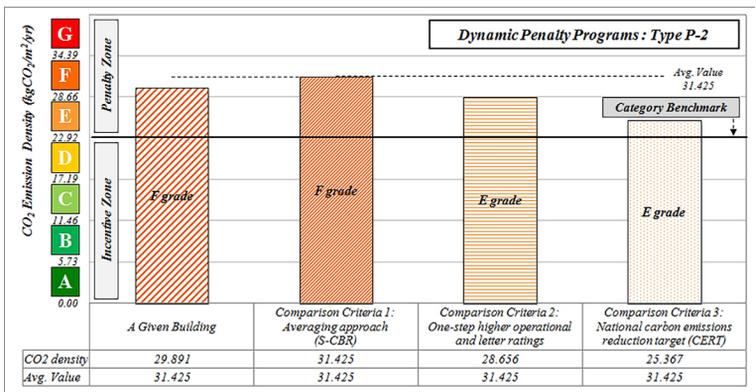


Fig. S15. Comparison chart for the penalty programs (actual CO2 emission density)