SEISMIC RISK ASSESSMENT OF EXISTING BUILDING STOCK IN ISTANBUL A PILOT APPLICATION IN ZEYTINBURNU DISTRICT

Guney Ozcebe[1], Haluk Sucuoglu[1], M. Semih Yucemen[1], Ahmet Yakut[1] and Joseph Kubin[2]

ABSTRACT

A multiple level assessment of the seismic vulnerability of several thousand buildings in Zeytinburnu, a district in Istanbul with much deficient construction, is presented. Consistent results are obtained from walkdown surveys as well as sophisticated discriminant analyses developed within the framework of NATO Science for Peace project SfP977231.

Introduction

In the past, severe earthquakes in Turkey and elsewhere have caused extensive losses of life and property. Determination of the addresses of seismically vulnerable buildings within the existing building stock is therefore a high priority task in the seismic risk reduction of the urban environment. Much effort has been devoted in recent years to the problem of how to devise reliable estimates, given the large uncertainties that exist, (Sozen and Hassan 1997, Gulkan and Sozen 1999 and Yucemen et al. 2004).

Current approaches in seismic vulnerability evaluation methods can be classified in three main groups depending on their level of complexity. The first, most simple level is known as "Walkdown Evaluation." Evaluation in this first level does not require any analysis and its goal is to determine the priority levels of buildings that require immediate intervention. The procedures in FEMA 154 (1988), FEMA 310 (1998) Tier 1 and the procedure developed by Sucuoglu and Yazgan (2003) are examples of walkdown survey procedures.

Preliminary assessment methodologies (PAM) are applied when more in-depth evaluation of building stocks is required. In this stage, simplified analysis of the building under investigation is performed based on a variety of methods. These analyses require data on the dimensions of the structural and nonstructural elements in the most critical story. The procedures by FEMA 310 (1998) Tier 2 and Ozcebe et al. (2003), later complemented by Yakut et al. (2003) can be listed as the examples of preliminary survey procedures. It is possible to survey large building stocks by employing the preliminary evaluation methodologies within a reasonable time span.

The procedures in third tier employ linear or nonlinear analyses of the building under consideration and require the as-built dimensions and the reinforcement details of all structural elements. The procedures proposed in FEMA 356 (2000), ATC 40 (1996), EUROCODE 8 (2004) and those by Sucuoglu et al. (2004) and Park and Ang (1985) are examples of third level assessment procedures.

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[1] Middle East Technical University, Dep't of Civil Engineering, 06531, Ankara, Turkey
[2] PROTA Software Ltd., METU - Technopolis, Silver Blocks B3, 06531 Ankara, Turkey

The built environment of Istanbul alone consists of about 1,000,000 buildings. It is anticipated that some 50,000 to 70,000 buildings in Istanbul are expected to experience severe damage or collapse if the probable scenario earthquake occurs, (JICA 2002). Within the scope of the project "*NATO SfP977231- Seismic Assessment and Rehabilitation of Existing Buildings*" the tools deemed to be essential for seismic safety assessment have been developed and made available to the profession, (Ozcebe et al. 2003 and Yakut et al. 2003). METU-EERC is completing the pilot implementation of the *"Earthquake Masterplan for the Istanbul Metropolitan Area"* in the Zeytinburnu district. Zeytinburnu, with a population of 240,000 and a building stock with more than 16,000 buildings, is one of the districts of Istanbul that possesses the highest seismic risk. An outline of the applied methodologies and the details of the project activities are provided in the paper.

The Walkdown Evaluation Procedure

This procedure was developed by Sucuoglu and Yazgan in 2003. The details of the procedure are available elsewhere (Sucuoglu 2003) and will not be repeated here. However, for the sake of completeness and the integrity of the work presented here, the proposed methodology will be given in the following paragraphs.

Structural parameters that have to be observed during the field surveys and the value given to each parameter by the observer are briefly given below.

Survey Parameters

(a) Number of Stories: This is the total number of floors above the ground level.

(b) Existence of a soft Story: A soft story usually exists in a building when one particular story, usually employed as a commercial space, has less stiffness and strength compared to the other stories.

(c) Existence of heavy Overhangs: Heavy balconies and overhanging floors in multistory reinforced concrete buildings shift the mass center upwards; accordingly give rise to increased seismic lateral forces and overturning moments during earthquakes.

(d) Apparent Building Quality: A close relationship has been observed between apparent quality [good, moderate, poor] and experienced damage during recent earthquakes in Turkey.

(e) Existence of short Columns: Frames with partial infills lead to the formation of short columns which sustain heavy damage since they are not designed for the high shear forces due to shortened heights that will result from a strong earthquake.

(f) Pounding Effect: When there is no sufficient clearance between adjacent buildings, they pound each other during an earthquake as a result of different vibration periods. Uneven floor levels aggravate the effect of pounding.

(g) Topographic Effects: Buildings on slopes steeper than 30 degrees have stepped foundations, which cannot distribute ground distortions evenly to structural members above.

(h) Local Soil Conditions: The intensity of ground motion at a particular site predominantly depends on the distance the causative fault and local soil conditions. As there exists a strong correlation between PGV and the shear wave velocities of local soils (Wald 1999), in this study the PGV is selected as to represent the ground motion intensity. The PGV map in the JICA (2002) report has contour increments of 20 cm/s^2. The intensity zones in Istanbul are expressed accordingly, in terms of the associated PGV ranges.

Zone I : $60 < PGV < 80$ cm/s^2
Zone II : $40 < PGV < 60$ cm/s^2
Zone III: $20 < PGV < 40$ cm/s^2

Based on their number of stories and the seismic hazard level at the site buildings are assigned different base scores as shown in Table 1.

Table 1. Base Scores and Vulnerability Scores for Concrete Buildings

Number of Stories	Base Scores (BS)			Vulnerability Scores (VS)					
	Zone I	Zone II	Zone III	Soft Story	Heavy Overhang	Apparent Quality	Short Column	Pounding	Topog. Effects
1 or 2	100	130	150	0	-5	-5	-5	0	0
3	90	120	140	-15	-10	-10	-5	-2	0
4	75	100	120	-20	-10	-10	-5	-3	-2
5	65	85	100	-25	-15	-15	-5	-3	-2
6 or 7	60	80	90	-30	-15	-15	-5	-3	-2

Building Seismic Performance

Once the vulnerability parameters of a building are obtained from walkdown surveys and its location is determined, the seismic performance score *PS* can be calculated by using Eq. 1. The base scores, *BS*, the vulnerability scores, *VS*, and the vulnerability score multiplies, *VSM*, to be used in Eq. 1 are defined in Tables 1 and 2, respectively

$$PS = (BS) - \Sigma \, (VSM) \times (VS) \qquad\qquad (1)$$

The weight of each building vulnerability parameter is evaluated by statistical procedures, based on the Duzce database[3]. The results are then smoothed, and the weights of the parameters for which there was no available data (soft story, pounding, topography) are assigned by using engineering judgment.

Table 2. Vulnerability Parameters, *(VSM)*

Soft story	Does not exist = 0; Exists = 1
Heavy overhangs	Does not exist = 0; Exists = 1
Apparent quality	Good = 0; Moderate = 1; Poor =2
Short columns	Does not exist = 0; Exists = 1
Pounding effect	Does not exist = 0; Exists = 1
Topograpic effects	Does not exist = 0; Exists = 1

Preliminary Assessment

In many instances statistical analysis based on the observed damage and significant building attributes would provide reliable and accurate results for regional assessments. Yucemen et al. 2004, Ozcebe et al. (2003) and Yakut et al. (2003) employed the discriminant

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[3] This database is available at http://www.seru.metu.edu.tr/archives/databases/Duzce_Database/

analysis technique to develop a preliminary evaluation methodology for assessing seismic vulnerability of existing low- to medium-rise RC buildings in Turkey. The main objective of the procedure is to identify the buildings that are highly vulnerable to damage. The procedure is applicable to RC frames and frame-wall structures, having up to seven stories. Definition of the discriminating parameters and the procedure to be followed are introduced below. Further details of the proposed method can be reached in the references mentioned above.

Definition of Parameters

The following parameters were chosen as the basic estimation parameters.

(a) Number of stories (n): This is the total number of individual floor systems above the ground level.

(b) Minimum normalized lateral stiffness index (mnlstfi): This index represents the lateral rigidity of the ground story, which is usually the most critical story. It is calculated by considering the columns and the structural walls at the ground story. The *mnlstfi* parameter shall be computed based on the following relationship:

$$mnlstfi = \min (I_x, I_y) \tag{2}$$

where;

$$I_{nx} = \frac{\sum (I_{col})_x + \sum (I_{sw})_x}{\sum A_f} \times 1000, \quad I_{ny} = \frac{\sum (I_{col})_y + \sum (I_{sw})_y}{\sum A_f} \times 1000 \tag{3}$$

where, $\Sigma(I_{col})_x$ and $\Sigma(I_{col})_y$ are the summation of the moment of inertias of all columns about their centroidal x and y axes, respectively. $\Sigma(I_{sw})_x$ and $\Sigma(I_{sw})_y$ are the summation of the moment of inertias of all structural walls about their centroidal x and y axes, respectively. I_{nx} and I_{ny} are the total normalized moment of inertia of all members about x and y axes, respectively. ΣA_f is the total floor area above ground level.

(c) Minimum normalized lateral strength index (mnlsi): It indicates the base shear capacity of the critical story. In the calculation of this index, unreinforced masonry filler walls are assumed to carry 10 percent of the shear force that can be carried by a structural wall having the same cross-sectional area (Sozen 1997). As in *mnlstfi* calculation, the vertical reinforced members with a cross-sectional aspect ratio of 7 or more are classified as structural walls. The *mnlsi* parameter shall be calculated by using the following equation:

$$mnlsi = \min (A_{nx}, A_{ny}) \tag{4}$$

where:

$$A_{nx} = \frac{\sum (A_{col})_x + \sum (A_{sw})_x + 0.1\sum (A_{mw})_x}{\sum A_f} \times 1000$$

$$A_{ny} = \frac{\sum (A_{col})_y + \sum (A_{sw})_y + 0.1\sum (A_{mw})_y}{\sum A_f} \times 1000 \tag{5}$$

For each column with a cross-sectional area denoted by A_{col}:

$$\left(A_{col}\right)_x = k_x \cdot A_{col} \quad , \quad \left(A_{col}\right)_y = k_y \cdot A_{col} \tag{5}$$

where; $k_x=1/2$ for square and circular columns; $k_x=2/3$ for rectangular columns with $b_x>b_y$; $k_x=1/3$ for rectangular columns with $b_x<b_y$; and $k_y=1-k_x$

For each shear wall with cross-sectional area denoted by A_{sw}:

$$(A_{sw})_x = k_x \cdot A_{sw} \quad , \quad (A_{sw})_y = k_y \cdot A_{sw} \tag{6}$$

where; $k_x=1$ for structural walls in the direction of x-axis; $k_x=0$ for structural walls in the direction of y-axis; and $k_y=1-k_x$

For each unreinforced masonry filler wall with no window or door opening and having a cross-sectional area denoted by A_{mw}:

$$(A_{mw})_x = k_x \cdot A_{mw} \quad , \quad (A_{mw})_y = k_y \cdot A_{mw} \tag{7}$$

where; $k_x=1.0$ for masonry walls in the direction of x-axis; $k_x=0$ for masonry walls in the direction of y-axis; and $k_y=1-k_x$

(d) Normalized redundancy score (nrs): Redundancy is the indication of the degree of the continuity of multiple frame lines which distribute lateral forces throughout the structural system. The normalized redundancy ratio (*nrr*) of a frame structure is calculated by using the following expression:

$$nrr = \frac{A_{tr}(nf_x-1)(nf_y-1)}{A_{gf}} \tag{8}$$

where; A_{tr} is the tributary area for a typical column. A_{tr} shall be taken as 25 m^2 if nf_x and nf_y are both greater than and equal to 3. In all other cases, A_{tr} shall be taken as 12.5 m^2. nf_x, nf_y are the number of continuous frame lines in the critical story (usually the ground story) in x and y directions, respectively. A_{gf} is the area of the ground story, i.e. the footprint area of the building.

Depending on the value of *nrr* computed from Eq. 8, the following discrete values are assigned to the normalized redundancy score (*nrs*):

$$nrs = 1 \text{ for } 0 < nrr \le 0.5$$
$$nrs = 2 \text{ for } 0.5 < nrr \le 1.0$$
$$nrs = 3 \text{ for } 1.0 < nrr$$

(e) Soft story index (ssi): On the ground story, there are usually fewer partition walls than in the upper stories. This situation is one of the main reasons for the soft story formations. Since the effects of masonry walls are included in the calculation of *mnlsi*, soft story index is defined as the ratio of the height of first story (i.e. the ground story), H_1, to the height of the second story, H_2.

$$ssi = \frac{H_1}{H_2} \tag{9}$$

(f) Overhang ratio (or): In a typical floor plan, the area beyond the outermost frame lines on all sides is defined as the overhang area. The summation of the overhang area of each story, $A_{overhang}$, divided by the area of the ground story, A_{gf}, is defined as the overhang ratio.

$$or = A_{overhang} / A_{gf} \tag{10}$$

Performance Classification

The damage index or the damage score corresponding to the life safety performance classification (DI_{LS}) shall be computed from the discriminant function given in Eq. 11.

$$DI_{LS}=0.620-0.246mnlstfi-0.182mnlsi-0.699nrs+3.269ssi+2.728or-4.905 \quad (11)$$

In the case of immediate occupancy performance classification (*IOPC*), the discriminant function, where DI_{IO} is the damage score corresponding to *IOPC*, based on these variables is:

$$DI_{IO}=0.808n-0.334mnlstfi-0.107mnlsi-0.687nrs+0.508ssi+3.884or-2.868 \quad (12)$$

In the proposed classification methodology, buildings are evaluated according to both performance levels. The steps to be followed are listed below.

(1) Calculate DI_{LS} and DI_{IO} scores by using Eq. 11 and Eq. 10, respectively.

(2) Determine the cutoff values for each performance classification by using Eq. 13. The LS_{CVR} and IO_{CVR} values in Eqs. 11 and 12 shall be obtained from Table 3 based on the number of stories above the ground level. The CMC values are adjustment factors, which introduce the spatial variation of the ground motion in the evaluation process. These values shall be taken from Table 4 based on the building location relative to the fault and the soil type at the site.

$$CV_{LS}=LS_{CVR}+\left|LS_{CVR}\right|\times(CMC-1); \quad CV_{IO}=IO_{CVR}+\left|IO_{CVR}\right|\times(CMC-1) \quad (13)$$

Table 3. Variation of LS_{CVR} and IO_{CVR} Values with Number of Stories

n	LS_{CVR}	IO_{CVR}
3 or less	0.383	-0.425
4	0.430	-0.609
5	0.495	-0.001
6	1.265	0.889
7	1.791	1.551

Table 4. Variation of CMC Values with Soil Type and Distance to Fault

Soil Type	Shear Wave Velocity (m/s)	Distance to Fault (km)				
		0-4	5-8	9-15	16-25	>26
B	>760	0.778	0.824	0.928	1.128	1.538
C	360-760	0.864	1.000	1.240	1.642	2.414
D	180-360	0.970	1.180	1.530	2.099	3.177
E	<180	1.082	1.360	1.810	2.534	3.900

(3) By comparing the CV values with associated DI value calculate performance grouping of the building for life safety performance classification (*LSPC*) and immediate occupancy performance classification (*IOPC*) as follows:

If $DI_{LS}>CV_{LS}$ take $PG_{LS}=1$
If $DI_{LS}<CV_{LS}$ take $PG_{LS}=0$
If $DI_{IO}>CV_{LS}$ take $PG_{IO}=1$
If $DI_{IO}<CV_{LS}$ take $PG_{IO}=0$

(4) To decide the probable expected performance level of the building the damage scores obtained from Eqs. 11 and 12 should be compared with the story dependent cutoff values obtained from Eq. 13. In each case, the building under evaluation is assigned an indicator variable of "0" or "1". The indicator variable "0" corresponds to "none, light or moderate damage" in the case of *LSPC* and "none or light damage" in the case of *IOPC*. Similarly, the indicator variable "1" corresponds to "severe damage or collapse" in the case of *LSPC* and "moderate or severe damage or collapse" in the case of *IOPC*. In the final stage, the building is rated in the "low risk group" if both indicator values are zero or in the "high risk group" when both indicator values are equal to unity. In all other cases buildings are classified as the cases "requiring further study." Further investigations have indicated that these buildings generally lie in the "moderate risk group."

The Earthquake Master Plan for Istanbul and the Zeytinburnu Pilot Project

Early in 2002, the Istanbul Metropolitan Municipality extended an invitation to a consortium formed by four leading Turkish universities to prepare a road map for the seismic risk mitigation in Istanbul, (*Earthquake Master Plan for Istanbul, EMPI, 2002).* These universities were the Middle East Technical University (METU), Istanbul Technical University, Bosphorus University and the Yildiz Technical University. An important aspect of the *EMPI* was the assessment of seismic vulnerability of existing building stock in Istanbul and to identify those buildings which will probably cause human losses in case of a severe earthquake. The Master Plan adopted a three tier seismic assessment methodology. It was also suggested that the validity and suitability of each tier should be checked by carrying out pilot area studies. The pilot implementation of the *EMPI* was adopted by the Zeytinburnu Municipality and it was referred to as the *"Zeytinburnu Pilot Project, ZPP."* The findings of a study carried under the auspices of the Japan International Cooperation Agency (2002) pointed out that among the 32 districts of Istanbul; Zeytinburnu possesses a high seismic hazard. About 17 percent of the entire building stock in Zeytinburnu is expected to experience severe damage or collapse in the case when the scenario earthquake defined in the JICA Report occurs. The multi-tier seismic safety assessment methodology developed by the *METU* was applied to all buildings in Zeytinburnu.

First Stage Evaluation (Walkdown Evaluation)

The walkdown survey yielded the complete inventory of the building stock in the Zeytinburnu district. At the end of this survey the buildings were identified in terms of their structural systems, their number of stories and their type of use. Walkdown survey results showed that there are currently 16,030 buildings in Zeytinburnu. 13,885 comprise RC buildings, 1,853 comprise masonry buildings, 135 were mixed construction and 143 were primarily steel construction. Table 5 catalogues the RC buildings with number of stories.

Table 5. Tabulation of RC Buildings According to the Number of Stories

Number of Stories	≤ 2	3	4	5	6	7	7+	Total
Number of Buildings	1,964	1,455	2,699	4,262	2,304	1,050	151	13,885

For Zeytinburnu, a scenario earthquake of magnitude 7.5 is assumed to take place in the Main Marmara Fault. The seismic hazard used in this study corresponds to an earthquake having 50 percent probability of exceedance within fifty years.

The walkdown survey yielded a preliminary seismic performance grading of the existing RC buildings in Zeytinburnu relative to each other. The calculated performance scores of the RC buildings with 7 stories or less are given in Table 6. This table shows that the performance scores of the buildings are inversely proportional with the number of stories. This response is in good agreement with the observations made in the aftermath of the recent earthquakes in Turkey.

From the spatial distribution of existing RC buildings in Zeytinburnu with respect to the calculated performance scores, it is observed that the majority of the buildings with seismic performance scores less than 20 are located along the Cirpici Creek, which provides a natural borderline for Zeytinburnu in the West. The seismic hazard along this creek is rather high and in this zone the PGV values vary between 50 m/s and 60 m/s. In the same manner, the seismic hazard along the coastal line is also high but the seismic risk in this region is not as high as on the east bank of the Cirpici Creek. This indicates that the proposed methodology is capable of reflecting the adverse effects of the seismic hazard and building attributes on the seismic performance classification of buildings.

Table 6. Calculated performance scores of RC buildings having 7 stories or less

Number of Stories	Performance Scores				Total
	PS ≤ 30	30 < PS ≤ 60	60 < PS ≤ 100	100 < PS	
1-2	0	0	248 (12.6)	1,716 (87.4)	1,964 (100.0)
3	0	41 (2.8)	1,005 (69.1)	409 (28.1)	1,455 (100.0)
4	28 (1.0)[1]	989 (36.6)	1,563 (57.9)	119 (4.4)	2,699 (100.0)
5	638 (15.0)	2,652 (62.2)	972 (22.8)	0	4,262 (100.0)
6	1,625 (70.5)	593 (25.7)	86 (3.7)	0	2,304 (100.0)
7	848 (80.8)	202 (19.2)	0	0	1,050 (100.0)
Total	3,139 (22.9)	4,477 (32.6)	3,874 (28.2)	2244 (16.3)	13,734 (100.0)

[1] Entries in parenthesis indicate the expected risk distribution in percentages.

Second Stage Evaluations (Preliminary Evaluation)

In this stage, buildings with a seismic performance score of 30 or less were given priority. There were 3,139 buildings in this group of which a representative sample of 2,397 buildings has been studied. In addition, 639 buildings with performance scores greater than 30 were also included in the analyses. The main reason of this inclusion was to assess the correlation between the methods used in the first and the second stage analyses.

In the second stage a total of 3,036 buildings were analyzed. Of these, 99 buildings had 3 stories or less, 332 were 4 storied, 929 had 5 stories, 1,147 had 6 stories 529 were 7 storied. Field teams gathered specific information about the structural system of each building including all dimensions of structural and nonstructural elements. This information was later tabulated in a

spreadsheet format and the preliminary assessment methodology (*PAM)* was applied. Table 7 shows that 2,098 buildings out of 3,036 (69.1%) were classified in the high seismic risk group.

The spatial distribution of those buildings which were classified in the high seismic risk group indicated that those buildings along the Cirpici Creek were among the most vulnerable ones. This is mainly because of the high seismic hazard of the region and poor building quality in this part of Zeytinburnu.

Table 8 compares the results of the walkdown and preliminary assessment methodologies. This table indicates that 1,738 (72.5 percent) of the 2,397 buildings with PS≤30 were classified in the high risk group, showing the consistency of the methodologies. The shifting of 659 buildings (26.5 percent) from high risk group to lower risk groups indicates that the application of *PAM* following the walkdown survey refines the results further.

Table 7. Results of the Preliminary Assessment Method

Number of Stories	High Risk Group	Moderate Risk Group	Low Risk Group	Total
≤3	10 (10.1)[1]	18 (18.2)	71 (71.7)	99 (100)
4	180 (54.2)	81 (24.4)	71 (21.4)	332 (100)
5	713 (76.7)	170 (18.3)	46 (5.0)	929 (100)
6	808 (70.4)	262 (22.8)	77 (6.7)	1,147 (100)
7	387 (73.2)	119 (22.5)	23 (4.3)	529 (100)
Total	2,098 (69.1)	650 (21.4)	288 (9.5)	3,036 (100)

[1] Entries in parenthesis indicate the expected risk distribution in percentages.

Inspection of Table 8 shows that as the performance score of a building gets higher, the probability of its being in the high risk group considerably decreases. This is clearly seen when PS≤30 buildings in Table 8 are compared with those with PS>100 buildings. In reality this was the required trend showing that the walkdown survey provides a realistic priority ordering.

Table 8. Comparisons between First and Second Stage Assessment Procedures

Risk Group	PS≤30	30<PS≤60	60<PS≤80	80<PS≤100	100<PS	Total
High	1,738 (72.5)	258 (66.2)	62 (48.8)	37 (35.6)	3 (16.7)	2,098 (69.1)
Moderate	503 (21.0)	81 (20.8)	32 (25.2)	29 (27.9)	5 (27.8)	650 (21.4)
Low	156 (6.5)	51(13.1)	33 (26.0)	38 (36.5)	10 (55.6)	288 (9.5)
Total	2,397 (100)	390 (100)	127 (100)	104 (100)	18 (100)	3,036 (100)

[1] Entries in parenthesis indicate the expected risk distribution in percentages.

Summary and Conclusions

This paper presents a seismic vulnerability assessment application on a regional scale. In the introductory parts of the manuscript a multi tier assessment methodology was summarized and in the second part the details of the field applications were introduced and the findings were presented.

The pilot implementation of the *"Earthquake Master Plan for Istanbul"* was made in the Zeytinburnu district of Istanbul. Of the 16,030 buildings surveyed in the first tier, 3,036 buildings were selected for further investigation in the second tier. At the end of the second tier

study 2,098 buildings (mostly having 4 stories or more) were rated in the high seismic risk group.

Comparisons made between the results of the first tier and the second tier investigations indicated that, in general, both methodologies yielded consistent results, which further indicated that walkdown survey provides a realistic priority ordering for the second tier investigations. Some buildings, which were assigned very high performance scores at the end of first tier, may be ranked in the high seismic risk group buildings by the second tier survey, which is also referred as *PAM* in this paper.

It was concluded that the walkdown evaluation procedure should be complemented by *PAM*. In doing this, those buildings with lower performance scores should be given priority and, in the long run, the entire building stock in the region should be screened by the use of *PAM*.

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