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Prediction of Indoor Natural Radiation Rates Due to Building Materials in Egyptian Buildings Using ANN

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ملخص البحث

استنشاق غاز الراوان داخل الأماكن المغلقه يعتبر من أهم المخاطر الصحيه التي يتعرض لها الإنسان. تعتبر مواد البناء المصدر الرئيسي لإنبعاث غاز الرادون و أشعه غاما داخل المنشآت و لذلك فإن الهدف الرئيسي من هذا البحث هو دراسة تأثير الخلطات الخرسانيه المختلفه و مواد الحوائط و الأرضيات على تركيز غاز الرادون و الجرعات الناتجه منه و التي يتعرض لها الإنسان و ذلك بعد تجميع بيانات عن محتوي النويدات المشعه و معدل انبعاث غاز الرادون في المواد الطبيعيه و المصنعه و التي تستخدم عادة في مصر حتى نستطيع السيطره على المخاطر الإشعاعيه التي يتعرض لها السكان و ذلك باختيار مكونات ونسب الخلطه الخرسانيه و مواد التشطيبات التي تؤدي لأقل جرعات إشعاعيه ممكنه.

ABSTRACT

Inhalation of indoor radon has been recognized as one of the health hazards. Building materials are considered the major sources of indoor radon and its daughters. Furthermore, building materials are considered the main source of gamma ray emission inside buildings.

The main objective of this research work was to study the effect of different concrete mixes, wall materials and flooring on indoor radon concentration and its associated doses after surveying for natural radionuclides content and radon exhalation rates in natural and manufactured building and decorative materials used commonly in Egypt. By using Artificial Neural Network technique (ANN) model was implemented to predict indoor radon concentration in a virtualized room built by different: concrete mixes, wall materials and flooring. The best network was achieved when the Mean Square Error (MSE) in validation performance plot reached 3.088e-06 at Epochs 32. The correlation coefficients are almost 0.999.

Key words: *Artificial Neural Network, Concrete Mixes, Indoor Radon Concentration*

1. INTRODUCTION:

The content of natural radionuclides namely, Radium ^{226}R, Thorium ^{232}Th and Potassium ^{40}K in building materials are natural sources of health hazards to building occupants. These contents contribute to the harmful radiation that would affect human health.

Knowledge about radon levels in buildings is the first step for protecting the health of anyone breathing the air. The World Health Organization declares that the pluralities of lung cancer are caused by inhalation of radon gas [1].

The relative indoor radon concentration and gamma radiations attributable to various sources which are: Building materials (80%), outside air (10%), water (5%), natural gas (1%) and liquefied petroleum gas (< 1%), [2]. Thus, in the present study, the contribution of building material as the main source of indoor radon concentration will be considered in order to assess the radiological hazards received by humans.

Recently, many studies have been carried out to determine the activity concentration in some building and finishing materials that commonly used in Egypt such as cement, coarse aggregate, sand, bricks, gypsum, ceramic, granite and marble. Measurements of activity concentrations in ordinary portland cement, sand, gravel, limestone, granite, marble, gypsum, clay bricks, cement bricks and ceramic have been carried out by Higgy (1995) [3]. Moreover, radium equivalents (Ra_{eq}) for all studied building materials were calculated. The results show that the average radium equivalents were 48.5, 18.5, 16.4, 20.2, 184, 10.4, 4.6, 78.2, 19.1 and 145 Bq/kg, respectively. It is clear that granite and ceramic have higher values of radium equivalent relative to other studied materials. Despite these higher values, they are less than the recommended value by UNSCEAR (370 Bq/kg) [4].

The variations of radon level in some houses in Alexandria city, Egypt were investigated by Abd El-Zaher, et al., (2008) [5]. In this work a set of indoor radon measurements was carried out in different houses built with the same type of building material. The results show that, the overall average value of radon concentration was (75.60 ± 9.44) Bq/m3, which is much less than the recommended ICRP, (1993) [6] action level 200-400 Bq/m3. Furthermore, the annual effective dose received by the resident is less than the range of action level (3-10 mSv/y) recommended by ICRP (1993) [6]. Furthermore, indoor radon survey of a total 15 randomly selected houses in Qena city, Upper Egypt was carried out by Hussein, (2006) [7]. The measured indoor radon level varied from 19 to 59 Bq/m^3 with an average of 40 Bq/m^3. An average annual effective dose of 0.56 mSv/y has been estimated and was found to be lower than the ICRP [6] action level (3- 10 mSv/y).

The harmful radiation effect of building materials comes from two ways: First by gamma radiation from ^{226}Ra, ^{232}Th, ^{40}K and their progenies and secondly, by releasing of radon and radon daughter. It is recommended that while characterizing the radiological hazard of the materials containing natural radioactivity, there should be no need to calculate annual effective dose due to gamma emission if Ra_{eq} has already been determined or vice versa [8]. Moreover, it is well established that the value of external hazard H_{ex} of building material is less than unity when, the corresponding value of Ra_{eq} is less than the upper limit (370 Bq/kg), [9].

Due to the above-mentioned reasons and the growing need to provide adequate public health safe guards to protect occupants of residential buildings from radiation hazards, this research is conducted with the following objectives:

- Developing an Artificial Neural Network model (ANN) to predicted total radon exhalation rate, radon concentration, annual absorbed dose rate and annual effective dose inside any built-up space.
- Studying the effect of different construction materials, finishing materials on indoor radon concentration, the annual absorbed dose rate and annual effective dose inside any closed space.

1. METHODOLOGY:

To achieve the objectives of the current study; data about concrete with different mix proportions and different types of coarse aggregates and mineral admixtures used in

Egypt were collected. Furthermore, data about natural radioactivity (^{226}Ra, ^{232}Th, ^{40}K) in concrete ingredients and interior finishing materials were also collected as well as radon exhalation to study the effect of using these materials on radon concentration and gamma emission inside buildings.

In this study, Neural Network Toolbox (nntool) case in Matlab software was used to train, validate and test the neural network. Excel software was used for data processing. Each input and output value has boundary limits from 0.0 to 1.0. Thus, data processing for input and output was described according to the following equation:

$$I_n = I_{actual} \ / \ I_{max} \ldots\ldots\ldots\ldots\ldots(1)$$

Where I_n is input value for training and testing, I_{actual} is the actual input data, I_{max} is the maximum value of a set of input data. Back – propagation neural network (BPNN) was employed for the ANN training in which Tansig function was used in each model as the nonlinear transfer function and the mean squared error (MSE) in the output layer as the convergence criteria. Furthermore, supervised training was applied in the process of developing the model. In this type, the neural network is supplied with inputs and the desired outputs. The response of the network is measured, then the weights are modified to reduce the difference between the actual and desired outputs. The set of all known samples is divided into two independent sets. First, training and validation set, which is a group of samples used to train the neural network. Second, testing set, which is a group of samples used to test the performance of the neural network and estimate the error between the output and the target.

Running the network consists of a forward pass and backward pass. In the forward pass, outputs are calculated and compared with desired output (Target). Errors from target and output are calculated. In the backward pass, these errors are used to modify weights in the network in order to reduce the size of the errors. Forward and backward passes are repeated until the errors are minimized.

2. DEVELOPMENT of ANN MODEL:

The NN Toolbox is one of the commonly used software tool for the development and design of artificial neural network. It can be open by entering command >> nntool. The basic steps in building ANN models by using (nntool software) can be summarized in the following steps:

- Step 1: (a) Click import data in the workspace and then select the input data from the excel sheet. Rename input data by I. (b) Then, select target/input data from the excel sheet and rename it by T. (c) Select the test data and rename it by S.

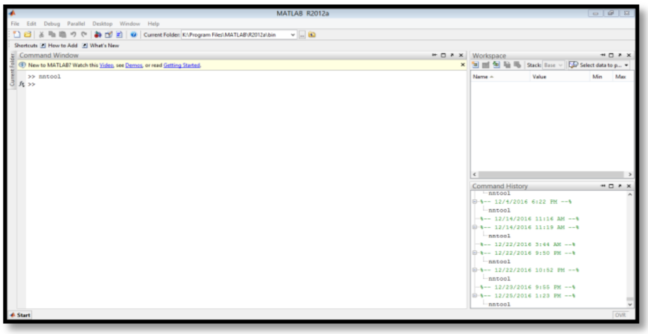


Fig.1 Command window

- Step 2: Type nntool in command window as in Figure 1. It will open NN Network/Data Manager screen. See Figure 2.
- Step 3: Click import button in Data Manager Screen to import input, target and sample (test) data from workspace.

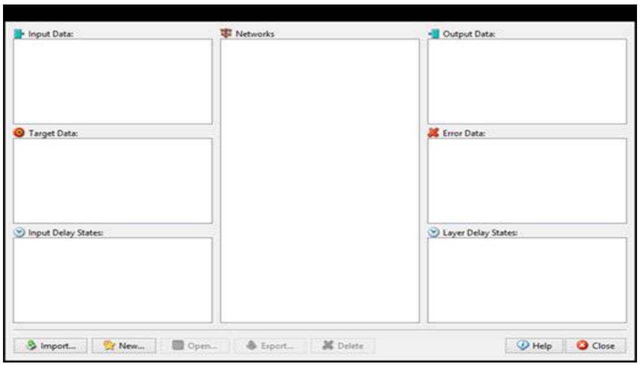


Fig.2 Data Manager Screen

- Step 4: Click New in Data Manager Screen to open Create Network or Data Screen select input and output data. Then, make sure the parameters are as indicated on the screen bellow and select number of neurons and transfer function (Figure 3).

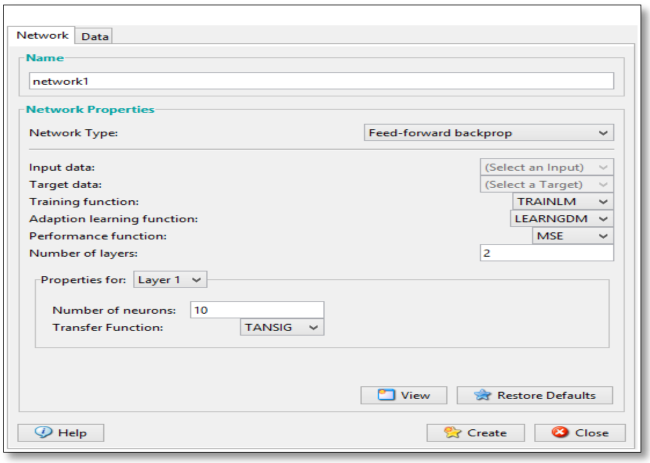


Fig. 3 Create Network Screen

- Step 5: Click create button to export network number to Data Manager Screen
- Step 6: Now, highlight network and then click open to start training. Confirm from view button number of neurons, inputs and outputs selected in step 5.
- Step 7: Click train then, select training data and training parameters (Epochs, goal, min grad and max. fail). Click Network button to start training. Figure 4 shows network training screen.
- Step 8: At the end of the training process, we can check the accuracy getting Performance, Training State and Regression plots (See Figure 5). Repeat step 4 to step 8 until error is minimized.
- Step 9: Now, the network has been trained successfully and is ready for simulation. Simulation is a way of testing on the network to see if it meets our expectation.
- Step 10: Create a new test data S on the ANN Network Manager and click simulate. Then check the simulation results.

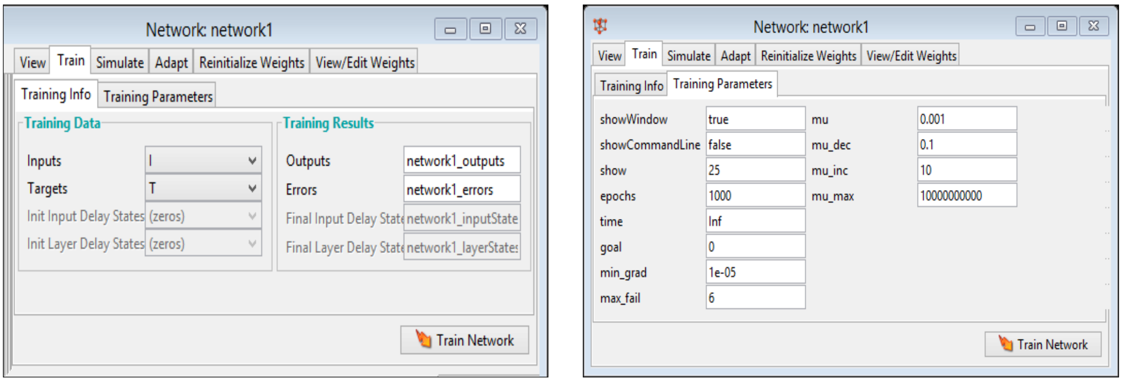


Fig. 4 Network Screen

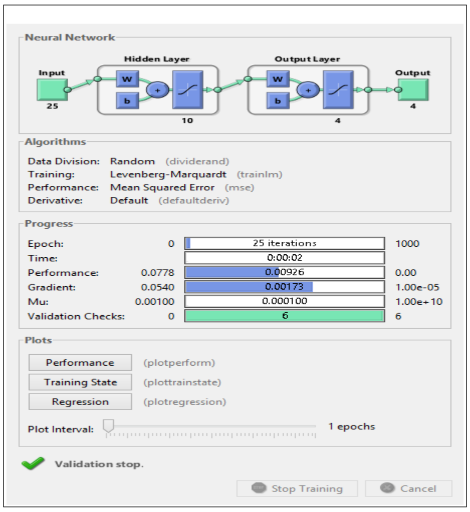


Fig. 5 Training Process

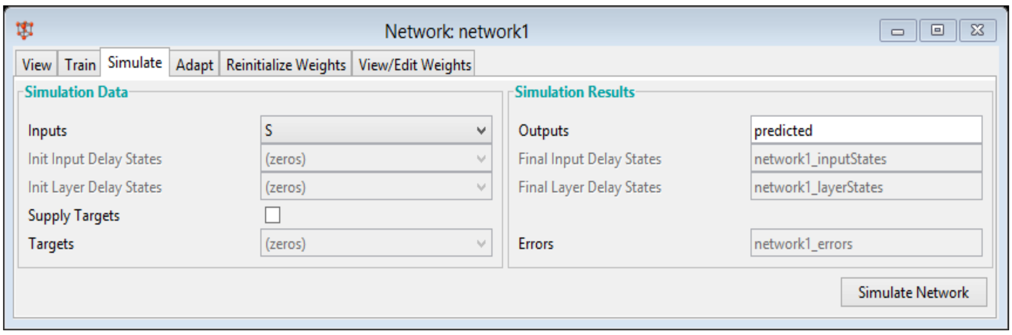


Fig 6 Simulation Process

ANN is created to simulate four outputs which are total radon exhalation rate emitted from all building materials, radon concentration, annual absorbed dose rate and annual effective dose inside room model. Table 1 illustrates the parameters, inputs and outputs (targets) data classifications of ANN.

Table 1 Parameters, Input and Output Data Classifications of ANN_2

Parameters	Input data classifications	Output data
Concrete Granite Marble Ceramic Porcelain Gypsum Clay bricks Cement bricks	Radon exhalation rate Room surface area	Indoor Total radon exhalation rate Radon concentration, Annual absorbed dose, Annual effective dose

It has been assumed that the room was built by 544 different applications by using 34 different concrete mixes and two types of bricks for walls and four different floor finishing materials. Also, assuming the case in which the design of gypsum false ceiling is applied. All these parameters are shown in Table 1. This means, the total number of data is 544 samples. 450 samples have been used for training and validating the network, the remainder have been used for simulation process. Method of arranging data in the excel sheet is clarified in Table 2.

Table 2 Arrangement of Data in Excel Sheet

<table>
<tr><td rowspan="9">INPUTS</td><td>Walls</td><td>Area m^2</td><td rowspan="13">450 Trading and Validating Data</td><td rowspan="9">94 Testing Data (Simulation)</td></tr>
<tr><td>Cement brick-Clay brick</td><td>Ex $Bqm\text{-}^2h\text{-}^1$</td></tr>
<tr><td>Ceiling</td><td>Area m^2</td></tr>
<tr><td>34 Concrete mixes – Gypsum</td><td>Ex $Bqm^{-2}h^{-1}$</td></tr>
<tr><td>Floor</td><td>Area m^2</td></tr>
<tr><td>Granite-Ceramic-Porcelain-Marble</td><td>Ex $Bqm^{-2}h^{-1}$</td></tr>
<tr><td>Column</td><td>Area m^2</td></tr>
<tr><td>34 Concrete mixes</td><td>Ex $Bqm^{-2}h^{-1}$</td></tr>
<tr><td>υ</td><td>0.5 (h^{-1})</td></tr>
<tr><td rowspan="4">OUTPUTS (Targets)</td><td>Total</td><td>Ex</td><td rowspan="4">?
Predicted</td></tr>
<tr><td>Rn^{-222}</td><td>Bq/m^3</td></tr>
<tr><td>D</td><td>mSv/y</td></tr>
<tr><td>H_E</td><td>mSv/y</td></tr>
</table>

Equation 1 was applied to all data in the excel sheet so that the values of input and output data are between 0.0 and 1.0. Parameters selected in Create Network Screen (Fig. 3) are as follows:

- Network Type = Feed-forward Backprop
- Train Function = TRAINLM
- Adaption Learning Function = LEARNGDM
- Performance Function = MSE

- Numbers of hidden Layers = 1 with 10 neurons and Tansig transfer function.

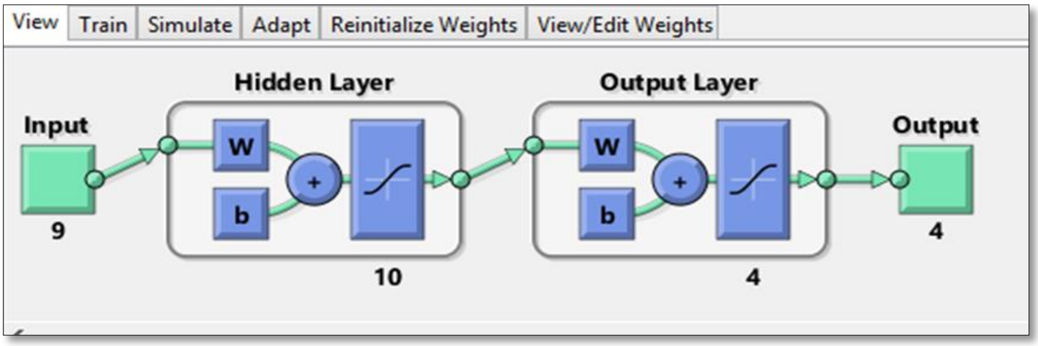
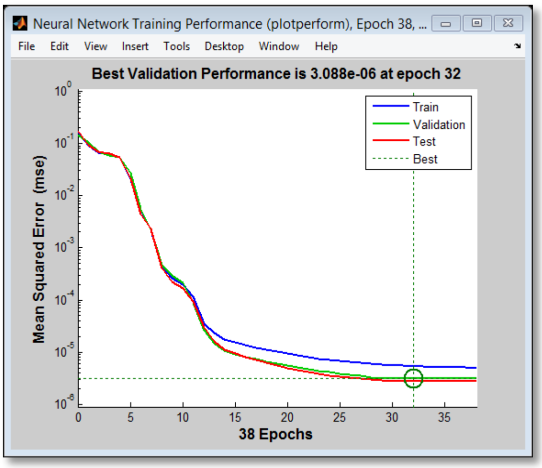


Fig. 7 Design of ANN Model

To create the design model, input I and target T were selected. On training parameters, the following parameters were selected: Epochs = 1000, goal = 0, max.fail = 6 and min. grad =1×e-5. The training process was repeated until the actual outputs (predicted) close to the targets. The best network was achieved when the Mean Square Error (MSE) in validation performance plot reached $3.088e^{-06}$ at Epochs 32 as shown in Figure 8. The plot shows closeness between the test and validation data which means good performance has been achieved. The training regression plots of training, validation and testing outputs relative to targets is shown in Figure 9. The correlation coefficients for the three outputs are almost 0.999. So, all outputs seem to track the targets reasonably very well which indicate that the designed model is capable of predicting our targets.



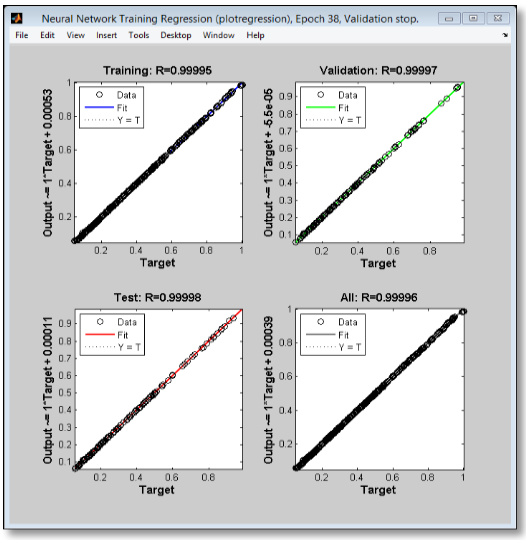


Fig 8 Performance Plot of ANN **Fig. 9 Neural Network Training Regression**

Thirty three different concrete mixtures were utilized alternately with wall materials which are cement bricks and clay bricks. Also, they were alternated with floor finishing material which are granite, marble, porcelain and ceramic. Table 3 illustrates the different types of concrete mixes used for creating ANN.

Table 3 Concrete Mixes Used in ANN Development

No	Conc.	Cement	w/c	Coarse Agg.		Fine Agg.	Mineral Admix.		Chemical Admix.	
	Code	Kg/m^3		Kg/m^3	Type	Kg/m^3	Kg/m^3	Type	ml/m^3	Type
1	C1	450	0.35	1702	magnetite	658	0	0	9000	W.R.
2	C5	315	0.34	1109	Artif. GGS	629	135	FA	1755+762	W.R+Sup.P
3	C7	300	0.5	1090	Basalt	925	0	FA	4091	W.R.
4	C8	280	0.45	1038	Basalt	881	70	FA	4454.5	W.R.
5	C10	411	0.28	1044	Natural	733	102.2	SF	5110	Sup. P.
6	C13	356	0.24	1109	Natural	801	53+53	FA+SF	5300	Sup. P.
7	C14	355	0.38	1102	Gravel	817	53	SF	1000	Sup. P.
8	C15	388.5	0.5	1260	Gravel	630	31	RHA	3818	Sup. P.
9	C16	228	0.7	927	Lightweight	890	97	RHA	0	0
10	C17	221	0.45	761	Lightweight	625	0	0	1316	Sup. P.
11	C19	189	0.3	1126	Natural	664	188	GGBFS	6000	Sup. P.
12	C21	168	0.55	980.5	Artif. GGS	504	168	GGBFS	2822	Sup. P.
13	C23	300	0.4	716	Artif. leca	635	30+20	FA+SF	0	0
14	C25	221	0.55	761	Artif. GGS	625	39	FA	0	0
15	C28	240	0.4	1030	Basalt	806	160	FA	1454.5	W.R.
16	C29	475.5	0.36	1391	granite	456.9	38.6	SF	4330	Sup. P.
17	C31	234	0.45	1126	Natural	566	11+132	SF+GGBFS	4500	Sup. P.
18	C32	385	0.25	1256	Limestone	454	165	SF	16500	Sup. P.
19	C34	300	0.4	717	Lightweight	635	20+30	SF+GGBFS	0	0
20	C38	514	0.36	1391.6	Dolomite	456.9	0	0	4330	Sup. P.
21	C39	436.9	0.36	1391.6	Dolomite	456.9	77.1	SF	4330	Sup. P.
22	C42	420	0.5	1260	Granite	630	100	FA	3818	Sup. P.
23	C43	325	0.63	940	Artificial	900	0	0	0	0
24	C44	260	0.68	930	Artificial	894	65	RHA	0	0
25	C45	189	0.4	1126	Natural	615	188	GGBFS	4500	Sup. P.
26	C46	300	0.3	1056	Natural	702	0	0	3272.7	W.R.
27	C47	384	0.58	1307	Granite	310	16	SF	0	0
28	C48	357	0.5	1260	Granite	630	63	RHA	3818	Sup. P.
29	C50	384	0.56	1306.5	Dolomite	302	23.5	SF	0	0
30	C51	437	0.32	1217.5	Dolomite	595	76.7	SF	4330	Sup. P.
31	C57	385	0.26	1198	Limestone	433	165	SF	16500	Sup. P.
32	C60	385	0.31	1069	limestone	386	83+165	FA+SF	16500	Sup. P.
33	C61	230	0.5	1100	Dolomite	750	150	FA	0	0

A comparison was carried out between ANN output and target. Table 4 displays targets, outputs of the tested samples as well as the percentage of absolute errors of the optimal trial.

Table 4 Targets and Outputs of ANN and Percentage of Absolute Error

No.	Total Radon Exhalation Rate Bq $m^{-2} h^{-1}$			Indoor Radon Concentration Bq/m^3			Annual Absorbed Dose mSv/y			Annual Effective Dose mSv/y		
	P	T	% ǀEǀ	P	T	% ǀEǀ	P	T	% ǀEǀ	P	T	% ǀEǀ
1	5.62	5.62	0.0	18.30	18.29	0.1	0.185	0.185	0.05	0.444	0.443	0.09
2	5.06	5.05	0.1	16.45	16.44	0.1	0.166	0.166	0.04	0.399	0.398	0.10
3	8.92	8.87	0.5	29.03	28.89	0.5	0.293	0.292	0.50	0.704	0.700	0.48
4	8.12	8.13	0.1	26.42	26.46	0.2	0.267	0.267	0.16	0.640	0.641	0.18
5	2.57	2.61	1.4	8.42	8.49	0.8	0.085	0.086	0.37	0.204	0.206	0.72
6	5.56	5.55	0.1	18.09	18.08	0.1	0.183	0.183	0.05	0.439	0.438	0.09
7	2.45	2.48	1.4	8.02	8.08	0.8	0.081	0.082	0.26	0.195	0.196	0.65
8	2.45	2.49	1.4	8.04	8.10	0.7	0.082	0.082	0.23	0.195	0.196	0.63
9	2.94	2.97	1.0	9.63	9.68	0.5	0.098	0.098	0.22	0.234	0.235	0.44
10	7.62	7.64	0.4	24.80	24.88	0.3	0.251	0.251	0.27	0.601	0.603	0.32
11	4.59	4.59	0.1	14.93	14.95	0.1	0.151	0.151	0.17	0.362	0.362	0.12
12	1.95	1.91	1.7	6.38	6.23	2.4	0.065	0.063	2.98	0.155	0.151	2.47
13	5.84	5.82	0.2	19.00	18.96	0.2	0.192	0.191	0.19	0.460	0.459	0.21
14	1.79	1.65	8.6	5.87	5.37	9.4	0.060	0.054	10.08	0.143	0.130	9.52
15	1.78	1.63	9.4	5.84	5.30	10.2	0.059	0.054	10.89	0.142	0.128	10.33
16	6.26	6.25	0.1	20.39	20.34	0.2	0.206	0.205	0.27	0.494	0.493	0.25
17	6.19	6.19	0.1	20.19	20.15	0.2	0.204	0.203	0.27	0.489	0.488	0.24
18	4.89	4.88	0.0	15.90	15.90	0.0	0.160	0.161	0.06	0.385	0.385	0.01
19	4.32	4.32	0.1	14.03	14.05	0.1	0.142	0.142	0.17	0.340	0.340	0.11
20	8.12	8.14	0.2	26.48	26.50	0.1	0.268	0.268	0.02	0.642	0.642	0.05
21	7.38	7.40	0.2	24.05	24.07	0.1	0.243	0.243	0.01	0.583	0.583	0.06
22	1.92	1.87	2.5	6.30	6.10	3.2	0.064	0.062	3.84	0.153	0.148	3.31
23	4.82	4.82	0.1	15.69	15.69	0.0	0.158	0.158	0.06	0.380	0.380	0.01
24	1.84	1.75	5.5	6.04	5.69	6.2	0.061	0.057	6.86	0.147	0.138	6.32
25	1.85	1.75	5.3	6.06	5.71	6.1	0.062	0.058	6.73	0.147	0.138	6.18
26	2.19	2.24	2.0	7.20	7.29	1.3	0.073	0.074	0.69	0.175	0.177	1.15
27	8.50	8.53	0.3	27.64	27.75	0.4	0.279	0.280	0.42	0.670	0.673	0.43

28	5.46	5.47	0.2	17.78	17.82	0.2	0.180	0.180	0.20	0.431	0.432	0.17
29	2.78	2.80	0.6	9.09	9.10	0.1	0.092	0.092	0.24	0.221	0.221	0.03
30	6.71	6.71	0.1	21.83	21.83	0.0	0.220	0.220	0.00	0.529	0.529	0.00
31	2.51	2.53	0.8	8.24	8.24	0.0	0.084	0.083	0.49	0.200	0.200	0.09
32	2.49	2.51	0.8	8.17	8.17	0.0	0.083	0.082	0.53	0.198	0.198	0.12
33	7.13	7.13	0.1	23.19	23.21	0.1	0.234	0.234	0.07	0.562	0.563	0.08
34	7.06	7.07	0.1	22.99	23.01	0.1	0.232	0.232	0.07	0.557	0.558	0.09
35	5.76	5.77	0.1	18.75	18.77	0.1	0.189	0.190	0.13	0.454	0.455	0.10
36	5.19	5.20	0.0	16.90	16.91	0.1	0.171	0.171	0.12	0.410	0.410	0.07
37	9.08	9.02	0.7	29.54	29.37	0.6	0.298	0.297	0.60	0.716	0.712	0.58
38	8.26	8.28	0.2	26.85	26.94	0.3	0.271	0.272	0.33	0.651	0.653	0.35
39	2.74	2.76	0.7	8.96	8.97	0.1	0.091	0.091	0.26	0.217	0.217	0.04
40	5.69	5.70	0.1	18.54	18.56	0.1	0.187	0.187	0.13	0.449	0.450	0.10
41	2.61	2.63	0.8	8.55	8.56	0.1	0.087	0.086	0.31	0.207	0.207	0.04
42	2.62	2.64	0.8	8.57	8.58	0.1	0.087	0.087	0.32	0.208	0.208	0.03
43	3.11	3.12	0.4	10.16	10.16	0.1	0.103	0.103	0.32	0.247	0.246	0.14
44	7.54	7.57	0.4	24.53	24.65	0.5	0.248	0.249	0.50	0.594	0.598	0.52
45	4.52	4.52	0.1	14.69	14.72	0.2	0.148	0.149	0.29	0.356	0.357	0.21
46	1.91	1.84	3.4	6.25	6.00	4.1	0.063	0.061	4.69	0.152	0.145	4.19
47	5.77	5.75	0.2	18.75	18.73	0.1	0.189	0.189	0.07	0.454	0.454	0.11
48	1.76	1.58	11.6	5.78	5.14	12.4	0.059	0.052	13.06	0.140	0.125	12.52
49	1.75	1.56	12.5	5.74	5.07	13.3	0.058	0.051	14.00	0.139	0.123	13.46
50	6.18	6.18	0.1	20.13	20.11	0.1	0.203	0.203	0.07	0.488	0.487	0.08
51	6.12	6.12	0.1	19.93	19.91	0.1	0.201	0.201	0.05	0.483	0.483	0.06
52	4.82	4.81	0.1	15.66	15.67	0.1	0.158	0.158	0.16	0.379	0.380	0.08
53	4.25	4.24	0.1	13.80	13.81	0.1	0.139	0.140	0.27	0.334	0.335	0.17
54	8.04	8.07	0.3	26.17	26.27	0.4	0.264	0.265	0.34	0.634	0.637	0.38
55	7.31	7.32	0.2	23.78	23.84	0.3	0.240	0.241	0.25	0.576	0.578	0.27
56	1.88	1.80	4.4	6.17	5.87	5.1	0.063	0.059	5.71	0.150	0.142	5.19
57	4.75	4.75	0.1	15.45	15.46	0.1	0.156	0.156	0.17	0.374	0.375	0.08
58	1.81	1.68	7.9	5.93	5.46	8.7	0.060	0.055	9.30	0.144	0.132	8.77
59	1.81	1.68	7.7	5.94	5.48	8.5	0.060	0.055	9.14	0.144	0.133	8.61
60	2.14	2.17	1.2	7.02	7.06	0.5	0.071	0.071	0.06	0.170	0.171	0.40
61	8.43	8.45	0.2	27.40	27.50	0.3	0.277	0.278	0.33	0.664	0.666	0.35

62	5.38	5.39	0.2	17.54	17.56	0.1	0.177	0.177	0.14	0.425	0.426	0.12
63	2.70	2.72	0.8	8.82	8.84	0.2	0.089	0.089	0.16	0.214	0.214	0.15
64	6.63	6.63	0.1	21.59	21.57	0.1	0.218	0.218	0.09	0.523	0.523	0.09
65	2.43	2.45	0.8	7.98	7.98	0.0	0.081	0.081	0.56	0.194	0.193	0.13
66	2.41	2.43	0.8	7.91	7.91	0.0	0.080	0.080	0.62	0.192	0.192	0.18
67	7.05	7.05	0.0	22.96	22.95	0.0	0.232	0.232	0.05	0.556	0.556	0.03
68	6.99	6.99	0.0	22.76	22.76	0.0	0.230	0.230	0.05	0.552	0.552	0.03
69	5.68	5.69	0.1	18.50	18.51	0.0	0.187	0.187	0.07	0.448	0.449	0.04
70	5.12	5.12	0.0	16.66	16.66	0.0	0.168	0.168	0.06	0.404	0.404	0.02
71	9.00	8.94	0.6	29.28	29.11	0.6	0.296	0.294	0.58	0.709	0.706	0.56
72	8.19	8.20	0.1	26.62	26.68	0.2	0.269	0.269	0.22	0.645	0.647	0.25
73	2.65	2.68	0.9	8.69	8.71	0.2	0.088	0.088	0.20	0.211	0.211	0.14
74	5.62	5.62	0.0	18.29	18.30	0.0	0.185	0.185	0.07	0.443	0.444	0.04
75	2.53	2.55	0.8	8.29	8.30	0.2	0.084	0.084	0.30	0.201	0.201	0.08
76	2.53	2.56	0.9	8.31	8.32	0.2	0.084	0.084	0.31	0.202	0.202	0.07
77	3.02	3.04	0.6	9.89	9.90	0.1	0.100	0.100	0.22	0.240	0.240	0.01
78	7.69	7.71	0.3	25.00	25.11	0.4	0.253	0.254	0.39	0.606	0.608	0.42
79	4.66	4.66	0.0	15.16	15.17	0.0	0.153	0.153	0.12	0.367	0.368	0.06
80	2.01	1.98	1.2	6.58	6.45	1.9	0.067	0.065	2.49	0.160	0.156	1.99
81	5.91	5.89	0.3	19.22	19.18	0.2	0.194	0.194	0.17	0.466	0.465	0.19
82	1.84	1.72	6.9	6.03	5.59	7.8	0.061	0.056	8.46	0.146	0.136	7.91
83	1.82	1.70	7.6	5.99	5.52	8.4	0.061	0.056	9.15	0.145	0.134	8.59
84	6.33	6.32	0.2	20.60	20.56	0.2	0.208	0.208	0.18	0.499	0.498	0.17
85	6.26	6.26	0.1	20.40	20.37	0.2	0.206	0.206	0.17	0.494	0.494	0.16
86	4.96	4.95	0.1	16.13	16.12	0.1	0.163	0.163	0.02	0.391	0.391	0.04
87	4.39	4.38	0.2	14.27	14.27	0.1	0.144	0.144	0.05	0.346	0.346	0.02
88	8.19	8.21	0.2	26.68	26.72	0.2	0.270	0.270	0.10	0.647	0.648	0.15
89	7.45	7.46	0.1	24.25	24.29	0.2	0.245	0.245	0.14	0.588	0.589	0.18
90	1.98	1.94	1.8	6.48	6.32	2.6	0.066	0.064	3.21	0.157	0.153	2.69
91	4.90	4.89	0.2	15.92	15.91	0.1	0.161	0.161	0.02	0.386	0.386	0.04
92	1.89	1.82	4.3	6.21	5.91	5.1	0.063	0.060	5.73	0.151	0.143	5.19
93	1.90	1.82	4.2	6.23	5.93	5.0	0.063	0.060	5.62	0.151	0.144	5.08
94	2.27	2.31	1.7	7.43	7.51	1.0	0.075	0.076	0.47	0.180	0.182	0.90

As shown in Table 4, the selected design model ANN can be used to predict the total surface radon exhalation rate emitted from building and decorative material, indoor radon concentration, annual absorbed dose and annual effective dose with average absolute error 1.4%, 1.5%, 1.6% and 1.5% respectively. The closeness between predicted values and targets for concrete exhalation rate, indoor radon concentration, annual absorbed dose and annual effective dose are presented in Figures 10, 11, 12, 13 respectively. It is obvious that the output results of the created network are close to the target with maximum correlation coefficient close to 1.

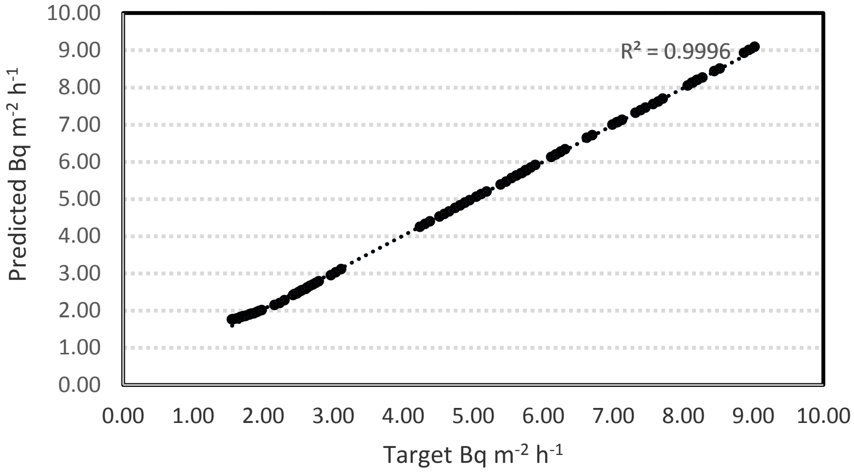


Fig. 10 ANN Response for Prediction of Total Radon Exhalation Rate

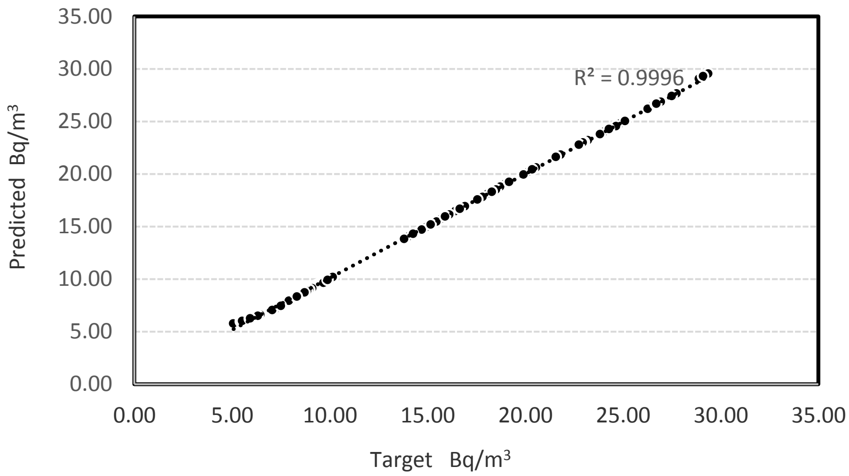


Fig. 11 ANN Response for Prediction of Indoor Radon Concentration

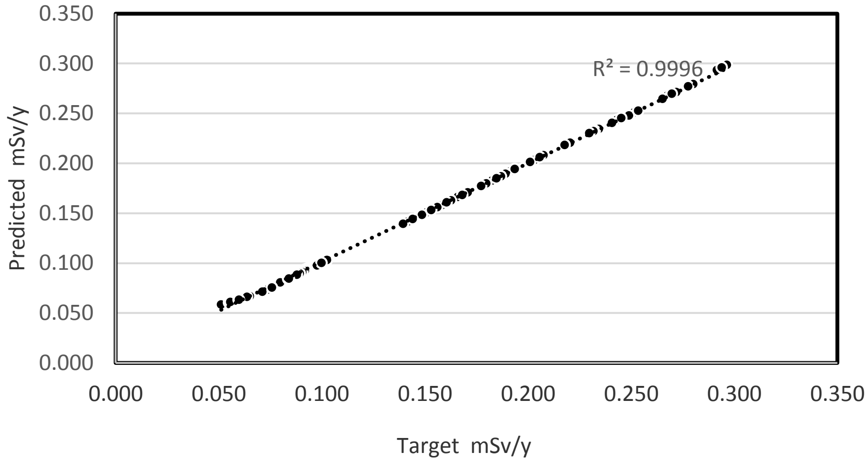


Fig. 12 ANN Response for Prediction of Annual Absorbed Dose

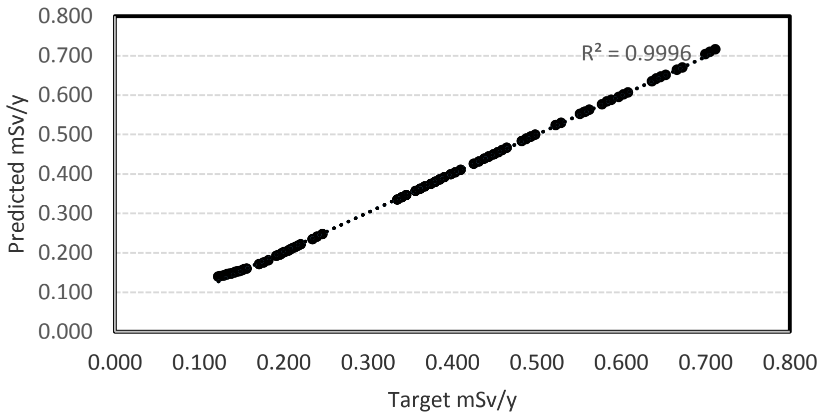


Fig. 13 ANN Response for Prediction Annual Effective Dose

3. RESULTS AND DISCUSSIONS:

A model room with dimensions 4×4×2.75m and having one window (1×1.4m) and one door (0.90×2.1m) is employed in a parametric study to investigate the effect of changing concrete constituents, finishing types and ceiling type on indoor radon concentration.

Impact based on types of aggregate

It was observed that the type of coarse aggregate used in concrete has a major effect on concrete radon exhalation rate and so affect the radon concentration. The effect of aggregate on radon concentration in case of using cement and clay bricks for building walls and using granite, marble, ceramic and porcelain for flooring were studied. Table 5 displays the indoor radon concentration due to utilizing different aggregate, bricks and flooring. Figures 14 and 15 represent the effect of altering walls and flooring materials with different types of concrete containing different types of coarse aggregate on indoor radon concentration. From data shown in Table 5 and clarified in the figures below, it is clear that:

- The maximum concentration of radon gas inside the room under study are at all the cases of using granite as a coarse aggregate no matter flooring types and wall materials.
- The minimum concentration of radon gas are at the cases of dolomite and limestone.
- The maximum radon concentration is 51.84 Bq/m^3 which is below the level allowed by (WHO) the **World Health Organization** (100 Bq/m^3). Also, it is below the reference level for homes (300 Bq/m3) recommended by **ICRP 115, (2010).**

Table 5 Effect of Coarse Aggregate, Flooring and Walls Material on Indoor Radon Concentration

Walls Material	Aggregate	Granite	Artificial	Leca	Basalt	LWA	HWA	Gravel	Dolomite	Limestone
	Flooring	Radon Concentration (Bq/m^3)								
Cement Bricks	Granite	50.61	44.23	42.74	39.50	37.70	26.30	16.51	14.45	13.32
	Marble	50.58	43.97	42.48	39.27	39.90	26.04	16.26	14.31	11.90
	Ceramic	47.10	41.13	39.64	36.40	34.10	23.20	13.41	9.10	10.20
	Porcelain	47.97	41.58	40.10	36.88	34.50	23.65	13.86	8.90	10.67
Clay Bricks	Granite	50.84	44.45	42.96	39.75	36.92	26.25	16.73	14.90	13.54
	Marble	51.84	44.19	42.70	39.49	36.66	26.26	16.48	14.09	13.28
	Ceramic	47.74	41.35	39.86	36.65	33.82	23.42	13.63	8.57	10.44
	Porcelain	48.19	41.80	40.31	37.10	34.27	23.87	14.09	9.02	10.89

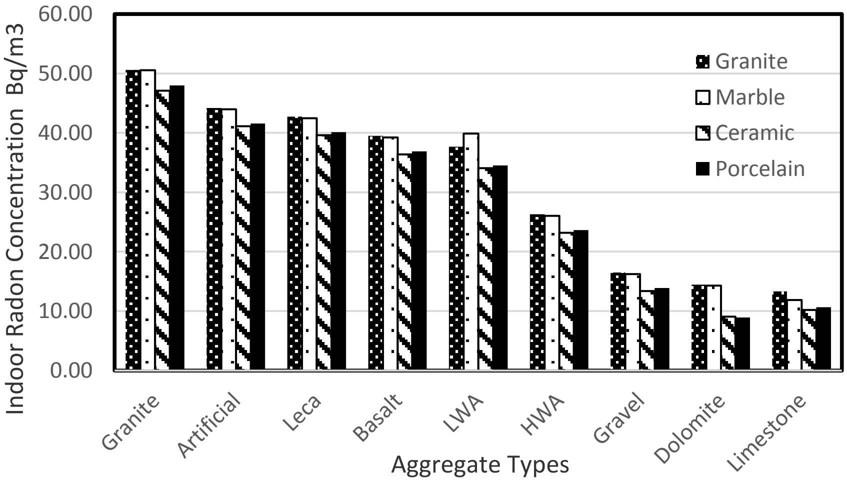


Fig. 14 Effect of Aggregate and Floor Finishing on Indoor Radon Concentration (cement bricks)

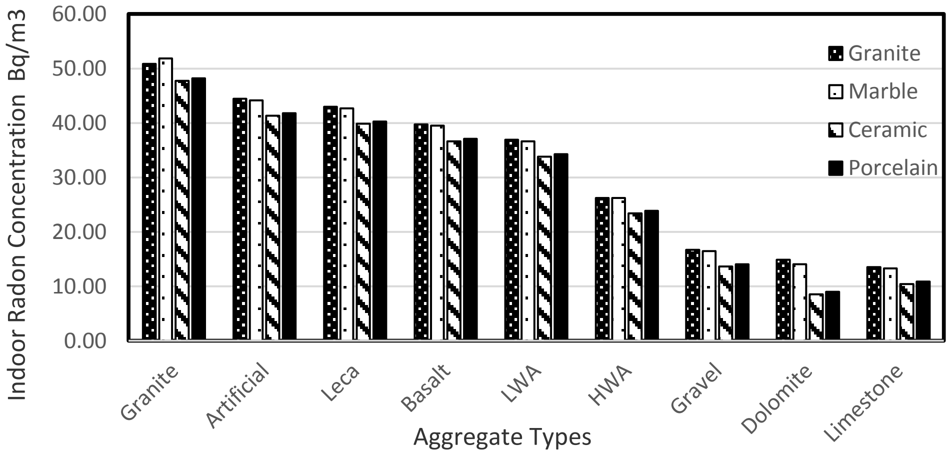


Fig. 15 Effect of Aggregate and Floor Finishing on Indoor Radon Concentration (clay bricks)

Impact based on types of bricks

From data listed in Table 5 and plotted in Figures 14 and 15, it is observed that using clay bricks in walls construction leads to a slight increase in radon concentration inside buildings. This increment can be ignored since all values are much less than the reference level for homes (300 Bq/m^3) recommended by ICRP 115, (2010) [10]**.**

Impact based on type of flooring

Granite, marble, ceramic and porcelain used as a flooring materials were altered with every type of concrete mixture and with each type of brick. It is observed that, for a certain type of concrete and brick indoor radon concentration vary with changing flooring material. Moreover, it is noticed that: 1. the maximum radon concentration is 51.84 Bq/m^3. This value is a result of using granite as a coarse aggregate in addition to use marble in flooring and clay bricks in wall construction. In addition we can notice that there is a slight difference in radon concentration in case of using either marble or granite as a flooring materials. 2. On the other hand, the lowest values of radon concentration are 8.57 Bq/m^3 and 8.90 Bq/m^3. These values are results of using dolomite in addition to ceramic with clay bricks and cement bricks respectively.

Impact of gypsum false ceiling

False ceiling is provided below the roof slab. It is usually provided for temperature control (heat insulation for AC), to install lights and conceal electrical cables. There are many types based on materials. The major type is gypsum false ceiling which commonly used in Egypt mainly for decoration purposes. The main properties of this type are: lightweight, sound insulated, fire resistance and thermal insulated. This study is aiming to determine radon exhalation rate from different types of materials used to construct a virtualized room and then estimate indoor radon concentration in order to detect any harmful radiation that would affect the human. Thus, radon exhalation rate from gypsum was investigated to study the effect of utilizing gypsum false ceiling on indoor radon concentration. As mentioned in the previous chapter, radon exhalation rate of gypsum is very low relative to that in concrete. Table 6 displays the estimated values of indoor radon concentration in two scenarios: First, concrete slab. Second, provide gypsum false ceiling below this slab. From data illustrated in Table 6, an average 44% reduction can be observed.

Bar chart is plotted in Figure 16 to clarify the great reduction in radon concentration when using gypsum ceiling.

Table 6 Effect of Gypsum False Ceiling on Indoor Radon Concentration

		Radon Concentration Bq/m^3			
Walls		Cement bricks			
Flooring		Granite		Marble	
Ceiling		Concrete	False Gypsum	Concrete	False Gypsum
Coarse Aggregate	Granite	50.61	27.53	50.58	27.27
	Artificial	44.23	24.33	43.97	24.08
	LECA	42.74	16.99	42.48	16.73
	Basalt	39.50	21.99	39.27	21.73
	LWA	37.70	20.57	39.90	20.31
	HWA	26.30	15.37	26.04	15.11
	Gravel	16.51	10.48	16.26	10.22
	Dolomite	14.45	7.95	14.31	7.69
	Limestone	13.32	8.88	11.90	8.62
	% Average Reduction	44%		44%	

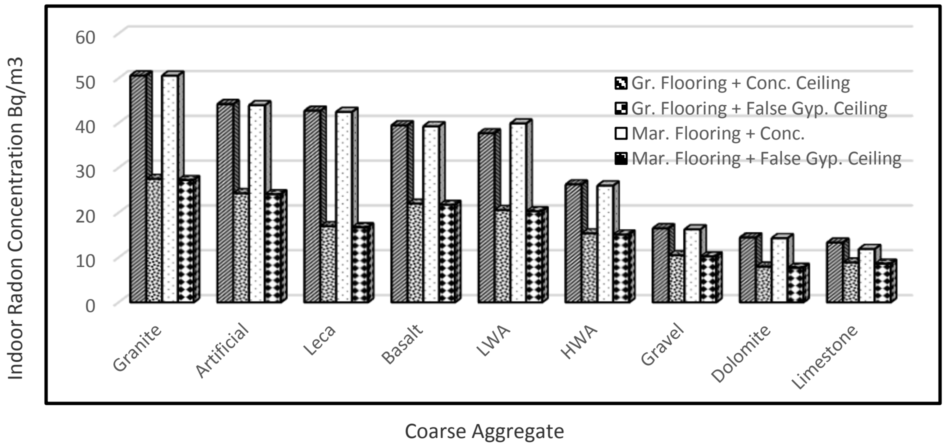


FIG. 16 The Effect of Gypsum False Ceiling on Indoor Radon Concentration

Impact of Building Material on Radon Doses

Impact based on types of aggregate

The effect of aggregate on radon annual absorbed and annual effective doses associated to indoor radon concentration in case of using cement and clay bricks for building walls and using granite, marble, ceramic and porcelain for flooring were studied. Table 7 and Table 8 display the annual absorbed dose and the annual effective dose, respectively, due to utilizing different aggregate, bricks and flooring.

Figure 17 to Figure 20 represent the effect of altering walls and flooring materials with different types of concrete containing different types of coarse aggregate on annual absorbed dose and annual effective dose.

Table 7 Effect of Coarse Aggregate, Flooring and Walls Material on Annual Absorbed Dose

Walls Material	Aggregate	Granite	Artificial	LECA	Basalt	LWA	HWA	Gravel	Dolomite	Limestone
	Flooring	Annual Absorbed Dose (mSv/y)								
Cement Bricks	Granite	0.511	0.447	0.432	0.399	0.381	0.266	0.167	0.146	0.135
	Marble	0.511	0.444	0.429	0.397	0.403	0.263	0.164	0.145	0.120
	Ceramic	0.476	0.415	0.400	0.368	0.344	0.234	0.135	0.092	0.103
	Porcelain	0.484	0.420	0.405	0.372	0.348	0.239	0.140	0.090	0.108
Clay Bricks	Granite	0.513	0.449	0.434	0.401	0.373	0.265	0.169	0.150	0.137
	Marble	0.524	0.446	0.431	0.399	0.370	0.265	0.166	0.142	0.134
	Ceramic	0.482	0.418	0.403	0.370	0.342	0.237	0.138	0.087	0.105
	Porcelain	0.487	0.422	0.407	0.375	0.346	0.241	0.142	0.091	0.110

Table 8 Effect of Coarse Aggregate, Flooring and Walls Material on Annual Effective Dose

Walls Material	Aggregate	Granite	Artificial	LECA	Basalt	LWA	HWA	Gravel	Dolomite	Limestone
	Flooring	Annual Effective Dose (mSv/y)								
Cement Bricks	Granite	1.227	1.072	1.036	0.957	0.914	0.637	0.400	0.350	0.323
	Marble	1.226	1.066	1.030	0.952	0.967	0.631	0.394	0.347	0.288
	Ceramic	1.142	0.997	0.961	0.882	0.826	0.562	0.325	0.221	0.247
	Porcelain	1.163	1.008	0.972	0.894	0.836	0.573	0.336	0.216	0.259
Clay Bricks	Granite	1.232	1.077	1.041	0.963	0.895	0.636	0.405	0.361	0.328
	Marble	1.256	1.071	1.035	0.957	0.889	0.636	0.399	0.341	0.322
	Ceramic	1.157	1.002	0.966	0.888	0.820	0.568	0.330	0.208	0.253
	Porcelain	1.168	1.013	0.977	0.899	0.831	0.579	0.341	0.219	0.264

From data shown in Table 8 and Table 9 and clarified in the figures below, it is clear that:

- The maximum absorbed and effective doses inside the room under study are at all the cases of using granite as a coarse aggregate no matter flooring types and wall materials.
- The minimum absorbed and effective doses are at the cases of dolomite and limestone.
- The estimated annual absorbed dose received by the residents of the room varies from 0.087mSv/y to 0.524mSv/y with an average of 0.306 mSv/y. Also, the estimated annual effective dose received by the residents varies from 1.256 mSv/y to 0.208 mSv/y with an average 0.732 mSv/y.
- The associated radon concentration doses are slightly higher in case of construct walls with clay bricks than cement bricks. So, these differences can be safely negligible.
- In all cases the estimated annual effective dose is less than even the lower limit of the recommended action level (3-10 mSv/y).

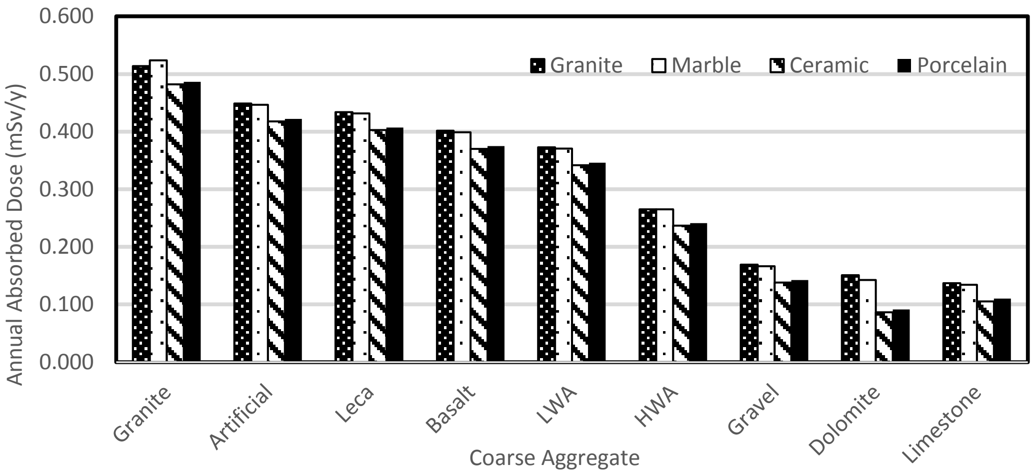


FIG. 18 Effect of Aggregate and Floor Finishing on Annual Absorbed Dose (Clay Bricks)

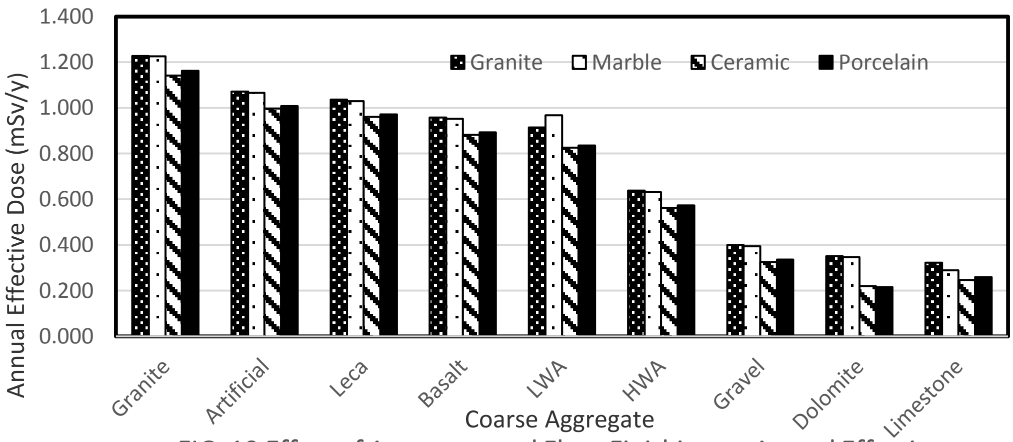


FIG. 19 Effect of Aggregate and Floor Finishing on Annual Effective Dose (Cement Bricks)

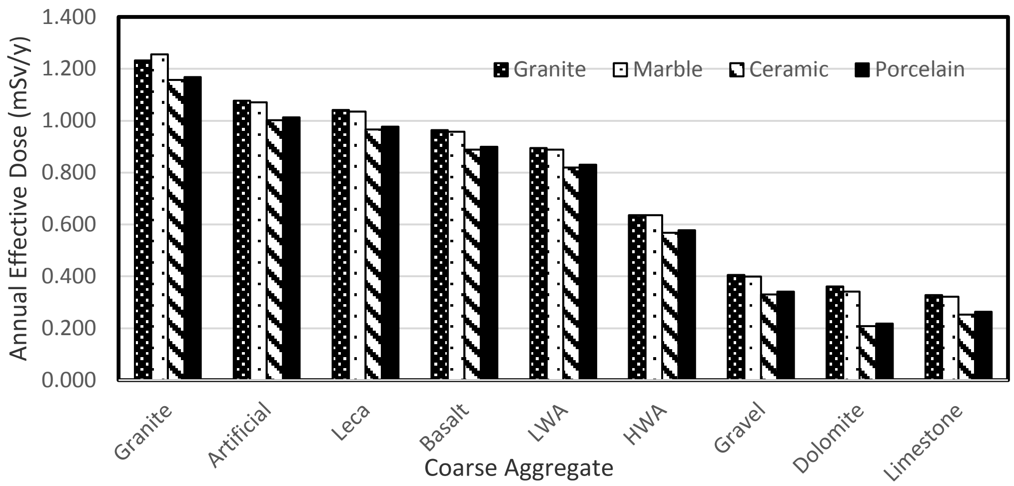


FIG.20 Effect of Aggregate and Floor Finishing on Annual Effective Dose (Clay Bricks)

5. Conclusions:

- Based on the outputs and the predicted data of the two models, it is concluded that the created networks with the parameters selected in Create Network Screen in both models appear a good response in predicting the mentioned targets.
- Results predicted from ANN showed that the highest values of radon concentration inside the room under study are at all the cases of using granite as a coarse aggregate. Moreover, the maximum values obtained in the case of utilizing granite coarse aggregate, marble flooring and granite flooring
- The predicted results also clarify that the minimum indoor radon concentration are estimated at the cases of utilizing dolomite and limestone as a coarse aggregates with ceramic and porcelain.
- Indoor radon concentration and the associated doses values are slightly higher in case of construct walls with clay bricks than cement bricks. So, these differences can be safely negligible.
- Providing Egyptian gypsum false ceiling below slab, causes about 44% reduction in indoor radon concentration.
- All the estimated values of radon concentration inside the virtualized room are approaching the values measured by Abd El-Zaher M., *et al*., (2008) in which the mean values of radon concentration in bedrooms and living rooms were 63.75 and 50.93 Bq/m3, respectively. Also, they are approaching the values measured by Abdel Ghany H. A., (2006) in which the mean values of radon concentration in bedrooms and living rooms were 53.18 and 50.98 Bq/m3, respectively.
- In all cases of room construction, the estimated annual effective dose is less than even the lower limit of the recommended action level (3-10 mSv/y).

- The values of indoor radon concentration and the associated doses obtained in the study were lower than the recommended safety limit, showing that the Egyptian building materials and finishing materials do not pose any important hazards and hence the use of these materials in construction is considered to be safe for resident of dwellings.

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